Scientific Agriculture

VOLUME 29

January 1949 - December 1949

Edited by the

AGRICULTURAL INSTITUTE OF CANADA
OTTAWA, CANADA

Published monthly by the authority of the Chairman of the National Committee on Agricultural Services

SCIENTIFIC AGRICULTURE

VOLUME 29 JANUARY, 1949 No. 1

FERTILITY STUDIES ON SOIL TYPES

I. SOME OBSERVATIONS ON CARLETON COUNTY INVESTIGATIONS[1]

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[Received for publication July 8, 1948]

In the past, field experiments of long-time duration conducted by the Experimental Farms Service and other institutions have given valuable information of wide application on the use of rotations, manure and commercial fertilizers in the maintenance of fertility. However, soils vary according to a combination of soil-forming factors as revealed by surveys, and information obtained on any one experimental site may not apply under different conditions. In addition to variations between types, soils also vary within types as a result of farm management. With this thought in mind, simple tests in co-operation with farmers on different soil types have been initiated throughout Canada. The discussion being presented herewith will be illustrated by reference to work being conducted in the vicinity of Ottawa, Carleton County, Ontario.

The soils of the County of Carleton in the Province of Ontario were surveyed during the summer and fall months of 1940 and the results were published as *Report No. 7* of the Ontario Soil Survey in March, 1944 (2). Since the survey was made, certain lines of investigation have been carried out in connection with some of the major soil types with a view to studying their relative present and potential fertility levels as well as the adaptation of different field crops for growth on these soils. This work has been conducted by the Division of Field Husbandry, Experimental Farms Service, in collaboration with the Division of Chemistry, Science Service. A paper containing some of the preliminary results was published in 1945 (1).

The objects of the investigations in Carleton County include the following:

(1) To obtain information on the levels of nitrogen, phosphorus, and potassium in these soils as measured by the response of different crops to these elements applied as fertilizers in field and greenhouse tests.

(2) To ascertain the best ratios of elements in fertilizer formulae, and the most desirable rates of application, for different crops on different soils in field tests.

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[1] Paper presented before the Soils Subject Division at the 28th Annual Meeting of the Agricultural Institute of Canada in Guelph, Ontario, on June 23, 1948. Joint contribution from the Division of Field Husbandry, Experimental Farms Service and the Division of Chemistry, Science Service. Scientific contribution No. 153, Division of Chemistry, Science Service.

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TABLE 1.—ESTIMATED YIELDS OF OATS AND HAY ON A NUMBER OF CARLETON COUNTY SOILS

Soil	Oat crop 1941-1947*		Hay crop 1941-1947	
	Number of fields	Bushels per acre	Number of fields	Tons per acre
Uplands sand	5	25	10	0.8
Rubicon sand	35	29	58	1.3
Kars gravelly sandy loam	61	35	51	1.3
Grenville loam	59	36	67	1.5
Manotick sandy loam	82	40	95	1.7
Castor silt loam	56	40	69	1.6
Osgoode loam	50	44	77	1.6
North Gower clay loam	71	43	91	1.8
Carp clay loam	105	47	122	2.0
Rideau clay	100	39	109	1.7

* No estimates for oat crop in 1944.

(3) To correlate chemical tests for phosphorus and potassium with crop response to these elements applied in greenhouse and field experiments.

(4) To obtain other chemical data, useful in evaluating the properties of the different soils.

The soil types on which work has been done in Carleton County may be described briefly as follows: (1) Uplands sand, an excessively drained acid sand; (2) Rubicon sand, an acid soil developed on an undulating plain, usually with rather imperfect drainage; (3) Kars gravelly loam, a light, excessively drained soil usually developed on gravelly ridges; (4) Manotick sandy loam, developed on an undulating plain of acid clay which has been covered by layers of fine sand and silt of varying depth, with the result that the cultivated layer may be rather variable in composition; (5) Castor silt loam, an imperfectly drained soil of intermediate texture; (6) Grenville loam, a well-drained morainic soil; (7) Osgoode loam, imperfectly drained and frequently occupying poorly drained basins between ridges of till; (8) Carp clay loam, a gently undulating soil with moderate to slow drainage; (9) North Gower clay loam, a poorly drained soil; and (10) Rideau clay, a very heavy, moderately drained, soil.

For the past few years estimates of the yields of oats and hay on a number of fields on the above soil types have been obtained. Tours were made through the more extensive areas of soil types, and estimates of the yields on the fields along the route were based on the observation of the agronomist. For the present purpose, only average yields for the period will be presented, although the relative rating of the different soils in any year varied with seasonal conditions. The average yields on each of a number of soil types are given for oats and hay in Table 1. These data, although based on a limited number of estimates, show the variation between the soil types in respect to the production of oats and hay crops, and emphasize the value of the survey in providing an inventory of soil conditions. The relative ratings of these soils as contained in the Soil Survey Report (2), are in good agreement with the data in Table 1.

GENERAL TECHNIQUE AND INTERPRETATION OF FIELD, GREENHOUSE AND LABORATORY TESTS

Field Experiments

Field tests with fertilizers for grain and hay crops have been located in co-operation with farmers on a few of the more important soil types. The land is prepared for seeding by the farmer. Application of fertilizers is made at the time of seeding, using a grain drill with fertilizer attachment. Each plot consists of two drill widths (15 feet), and is located at right-angles to the direction of plowing so as to eliminate the variation between plots, resulting from crowns and dead furrows, an appreciable source of error in the case of many imperfectly drained soils with level topography. The lengths of these plots may vary from farm to farm but approximate 200 feet. The yields of each crop are obtained by sampling of the plots. Samples are taken at random except on the plots of grain seeded to hay where crowns and dead furrows cross the plots, in which case the sampling points in the different plots within a block are in a straight line at right-angles to the length of the plots. This technique employed for grain and hay crops on these soils is satisfactory, particularly when the treatments are replicated two or three times.

Different farms on the same soil type may vary considerably in fertility because of differences in farm management. In 1945 on a Castor silt loam, the check plots on one farm gave a yield of 10.7 bushels of oats per acre; but on another farm on the same soil type, the yield on the check plots was 80.6 bushels per acre. Thus, in many cases the different farms on the same soil type cannot be considered as replications, and it is desirable to obtain fairly precise results on each farm, in order to learn the specific effect of the treatments. However, each of these tests is not considered as a self-contained experiment, nor is a rigid interpretation by statistical methods applied to the data, although the experimental error is calculated and considered in arriving at conclusions. Observation of the data in any of these tests with consideration of other information on the soil, is the approach being followed in regard to interpretation.

Greenhouse Experiments

The soils for greenhouse studies consist of composite samples of surface soil from twenty distributed points in the case of each field selected. The soils are air-dried, passed through a sieve with one-half inch mesh, mixed, and placed in glazed gallon pots on a volume basis. Oats and alfalfa are seeded together in December and later thinned to seven plants of oats and ten of alfalfa per pot. Fertilizers are placed in the soil in a layer at a depth of two inches, oat seeds at a depth of one inch and alfalfa seeds at a depth of one-half inch. The treatments are randomized in each of three replications. The oat crop is harvested in the spring and during the summer three crops of alfalfa are obtained.

Several factors relating to greenhouse technique have been studied. Observations of the performance of crops under field conditions on the different soils are kept in mind in interpreting greenhouse data. In a general way, the trends of response to the different elements on the different soils have been similar under field and greenhouse conditions, although

TABLE 2.—AVERAGE YIELDS OF GRAIN FROM OATS ON DIFFERENT SOILS UNDER FIELD AND GREENHOUSE CONDITIONS

Soil	Greenhouse tests Check pots, 5 fields	Estimated field yields 1941-1947, excepting 1944	
	Yield in grams per pot	Number of fields	Yield in bushels per acre
Kars gravelly sandy loam	4.8	61	35
Castor silt loam	1.8	56	40
North Gower clay loam	3.3	71	43
Carp clay loam	3.8	105	47
Rideau clay	5.7	100	39

TABLE 3.—INCREASES IN GRAIN YIELDS FROM NITROGEN AND PHOSPHORUS TREATMENTS IN FIELD AND GREENHOUSE TESTS ON TWO SOILS

Kind of test	Treatments in pounds per acre*			Increases in grain yield			
				Castor silt loam (one farm)		North Gower clay loam (average two farms)	
	N	P_2O_5	K_2O	N	P_2O_5	N	P_2O_5
				%	%	%	%
Field	16	48	48	48	42	11	9
Greenhouse	16	40	40	82	673	21	74

* Elements applied singly and in each combination.

exceptions occur, and the degree of response may be of greater magnitude in the greenhouse in some cases. The variation in performance of some soils under field and greenhouse conditions is illustrated by data in Table 2.

On the Rideau clay and the Kars gravelly sandy loam, good grain yields have been produced in the greenhouse. The relatively higher rating of the Kars soil in the greenhouse than on the basis of field performance is probably the result of more favourable moisture conditions for this soil under greenhouse conditions. On the Castor silt loam, North Gower clay loam, and Carp clay loam, receiving no fertilizer, relatively poorer yields of oats have been produced in the greenhouse than might have been expected on the basis of yields in the field.

In field tests in 1946 on Castor silt loam and on North Gower clay loam, and in greenhouse tests on similar soils obtained in the fall of the same year from the same farms though on different fields, the oat crops responded to both nitrogen and phosphorus but not to potassium. The percentage increases in grain yields from nitrogen and from phosphorus treatments on these soils in the field and greenhouse tests are presented in Table 3. It is to be noted that, on these soils, phosphorus became more of a limiting factor in the greenhouse than in the field tests.

On the Kars gravelly loam, and Rideau clay, where good yields of grain were produced in the greenhouse (Table 2), the response to phosphorus was slight as will be shown later in this paper.

TABLE 4.—PHOSPHORUS CONTENT OF GRAIN FROM OAT CROP ON DIFFERENT SOILS IN THE GREENHOUSE

(All soils received 400 lb. per acre of 4-0-10 fertilizer)

Soil	Number of tests	Phosphorus in grain
		% P.
Kars gravelly sandy loam	3	0.34
Castor silt loam	3	0.29
North Gower clay loam	3	0.29
Carp clay loam	3	0.28
Rideau clay	3	0.37

TABLE 5.—ROOT YIELDS FROM AN OAT CROP ON DIFFERENT SOILS IN THE GREENHOUSE

(Air-dry weights of roots, when vegetative top growth measured approximately 18 inches)

Soil	Treatments	
	4-0-10 (Grams of roots per pot)	4-10-10 (Grams of roots per pot)
Uplands sand	1.4	2.0
Rubicon sand	1.2	1.5
Kars gravelly sandy loam	1.4	1.7
North Gower clay loam	0.6	0.7
Carp clay loam	0.7	1.0
Rideau clay	0.5	0.7

TABLE 6.—EFFECT OF DIFFERENT SUBSOILS ON THE YIELDS OF OATS AND ALFALFA GROWN IN THE GREENHOUSE

(Yields based on six replications)

Subsoils	Grain grams per tile	Three crops of alfalfa grams per tile (air-dry)
Clay	11.5	9.6
Loam	16.0	14.5
Sand	8.6	10.5

Data in Table 4 indicate that the phosphorus content in the grain of oat crops grown in the greenhouse on Kars gravelly sandy loam and Rideau clay was higher than that of the grain produced on Castor silt loam, North Gower clay loam, and Carp clay loam. The foregoing results suggest the possibility that a limited supply of soil phosphorus may be a contributing factor to the poor performance of certain soils under greenhouse conditions.

The greater root growth occurring in soils of lighter texture, as shown in Table 5, may compensate to some extent for lower levels of nutrients in such soils. The data on each soil type were based on three tests on soil from different farms. The treatments were applied on the basis of 400 lb. of 4-10-10 per acre.

TABLE 7.—EFFECT OF DIFFERENT FERTILIZER TREATMENTS ON YIELDS OF OATS IN FIELD TESTS ON FOUR SOIL TYPES

(Yields in bushels per acre)

Soil	Number of tests 1944-1946	Average yields		Increases from 4-12-12		Average increases from fertilizer elements		
		Check	4-12-12*	Average	Maximum in any test	Nitrogen	Phosphorus	Potassium
Uplands sand	6	14	27	13	21	9	2	1
Rubicon sand	4	28	37	9	9	4	3	3
Castor silt loam	6	35	48	13	18	6	5	1
North Gower clay loam	4	46	52	6	16	5	3	−3

* Four hundred pounds per acre.

In the application of greenhouse results to field problems the absence of subsoil in greenhouse tests is worthy of consideration. The effect of different subsoils on the yields of oats and alfalfa grown in the greenhouse on a uniform surface soil in tiles, containing clay, loam, and sand subsoils to a depth of two feet, is shown by the data in Table 6. The variation in yields indicates that the subsoils had an appreciable influence on the growth of these crops.

Comparisons of field responses to fertilizers with those obtained in the greenhouse, on soils from the same field experimental sites, are being made. In the one comparison available in 1947, both field and greenhouse tests, based on the same field on Castor silt loam, indicated the superiority of 8-12-4 and 8-8-8 ratios over a number of other fertilizer ratios, for an oat crop. In the field test the increases over the check were 19 and 17 bushels per acre, representing increases of 70 and 63 per cent for the 8-12-4 and 8-8-8 ratios, respectively. In the greenhouse test the increases over the check for the 8-12-4 and 8-8-8 ratios were 311 and 254 per cent, respectively. Although not a measure of the degree of response the greenhouse test has indicated the trend of response to be expected under field conditions.

Information on the reliability of greenhouse results, and on the different factors contributing to discrepancies between greenhouse and field results, should be valuable in the interpretation of greenhouse data in relation to field conditions. The effect of the presence of subsoils on the response of oats and alfalfa to fertilizer treatments applied to the surface soils, and the effects of air-drying of soils for a period of four weeks prior to seeding as followed in current greenhouse procedure, are factors being studied.

Laboratory Studies

The importance of combining laboratory studies with field and greenhouse work of the nature just outlined is widely recognized. In the past it has seldom been possible to bring this about in such an extensive study. Examination of the soils under investigation will supply a great deal of information which will be useful in interpreting some of the observations made, as well as giving fundamental results on the variation to be found between and within soil types. The determination of soil reaction, amounts

TABLE 8.—EFFECT OF FERTILIZER TREATMENTS ON OATS IN 1946, AND ON SUCCEEDING HAY CROP IN 1947, ON FOUR SOIL TYPES

(Grain in bushels per acre, and hay in pounds of dry matter per acre)

Soil	Farm	Yields				Increases from fertilizer elements					
		Check		4-12-12 400 lb. per ac.		Nitrogen		Phosphorus		Potassium	
		Grain	Hay	Grain	Hay	Grain	Hay	Grain	Hay	Grain	Hay
Uplands sand	*Quinn	14	2920	35	—	15	−576	3	347	2	526
Rubicon sand	Hawkins	30	2316	39	2927	5	−193	3	466	3	394
Castor silt loam	Waddell	11	1360	22	2142	5	−171	5	888	−1	104
North Gower clay loam	Kenny	50	2001	66	3291	9	− 12	9	1098	−2	128

* The hay yield data for the 4-12-12 treatment on this farm were not reliable, and were discarded.

of organic matter, nitrogen, phosphorus and exchangeable bases, and mechanical composition, should give a more detailed picture of the soils with which the agronomist is working. On the other hand, results of controlled experiments in field and greenhouse can be extremely useful in supplementing laboratory investigations. For example, the value of studies on soil colloids and soil organic matter is very much enhanced when results can be compared with the agronomic behaviour of the soils in question.

In the work under discussion, measured response to fertilizer applications is being compared with determinations of so-called "available" phosphorus and potassium by a variety of methods. Many procedures have been suggested for estimating the availability of these plant nutrients in soil and some have been used fairly extensively with more or less success. However, the universal applicability of such methods is questionable. Tests found suitable in one region may be entirely unsuitable in another and methods which will work on acid soils, for example, may give results leading to erroneous conclusions on alkaline soils. What appears to be lacking is a sufficiently large volume of data for any of these methods on a wide variety of our soil types on which measured response to applications of phosphorus and potassium has been obtained. This is being attempted on the Carleton County soils and will be extended to other areas as time and opportunity permit.

DISCUSSION OF RESULTS FROM FIELD, GREENHOUSE AND LABORATORY TESTS ON DIFFERENT SOIL TYPES

Response of Oats and Hay Crops to N, P and K in Field

Field tests relating to fertilizer treatments for oats and subsequent hay crops were conducted on four soil types from 1944 to 1946, inclusive. Nitrogen, phosphorus, and potassium were applied alone and in combination, at the rates represented for each element by 400 lb. per acre of a 4-12-12 fertilizer. The response of the crop to each of the elements N, P and K represented the increase in yield due to that element when used alone and with each of the other elements. Thus, for nitrogen, the increase

TABLE 9.—RESPONSE OF OATS AND ALFALFA TO NITROGEN, PHOSPHORUS, AND POTASSIUM ON DIFFERENT SOIL TYPES, IN THE GREENHOUSE

(Grain in grams per gallon pot, and alfalfa as total air-dry weight of three cuttings in grams per pot)

Soil*	Yields				Increases from fertilizer elements					
	Check		4-10-10		Nitrogen		Phosphorus		Potassium	
	Oats	Alfalfa	Oats	Alfalfa	Oats	Alfalfa	Oats	Alfalfa	Oats	Alfalfa
Uplands sand	1.8	11.5	4.7	12.4	2.3	−4.3	0.2	0.2	0.3	3.3
Rubicon sand	3.7	10.8	5.1	22.7	1.3	−1.1	0.2	6.0	0.0	6.8
Kars gravelly sandy loam	6.0	26.9	8.0	33.7	2.3	−1.7	−0.5	3.2	−0.2	5.2
Grenville loam	4.4	19.7	8.9	29.0	1.3	0.1	3.1	6.2	0.1	0.7
Manotick sandy loam	3.6	12.5	8.1	20.7	1.4	−1.6	2.6	6.3	0.0	3.0
Castor silt loam	1.4	7.2	5.6	15.4	1.4	−1.1	2.9	5.7	0.1	4.7
Osgoode loam	4.2	15.4	7.8	23.7	1.7	−1.6	2.2	7.9	−0.5	1.9
Carp clay loam	3.9	18.5	7.7	25.9	2.0	−1.5	1.9	8.3	0.3	0.8
North Gower clay loam	3.4	11.0	7.9	23.6	1.1	−1.1	3.6	12.4	−0.3	0.9
Rideau clay	5.1	25.3	7.8	25.9	2.1	−1.8	0.8	3.0	−0.2	−0.2

* Each soil type represented bv tests on soil from three farms.

of the N-treated plot over the check was determined, also that for NP over P, for NK over K, and for NPK over PK. The average of these has been taken as a measure of the response to nitrogen treatments. Similar calculations were made for the elements P and K. The results obtained in 1944 and 1945 were from unreplicated treatments in plots 15 feet in width and extending the length of the fields, but in 1946 the treatments were replicated three times, using the design referred to earlier in the discussion of technique. A summary of the effect of treatments on yields of oats is presented in Table 7. Although variations in results occurred between tests on the same soil type, and in different years which are not shown in Table 7, the data indicate an increase in grain yields from nitrogen and from phosphorus, with a trend for greater increases from nitrogen than from phosphorus, especially on the excessively drained Uplands sand. There was little response by the oat crop to potassium except on Rubicon sand, where a small but consistent trend for response to this element occurred in each of the four tests. The trends for response to nitrogen were more consistent in regard to the different tests on the same soil type than those for phosphorus. The yields for the check and the 4-12-12 treatment show the variation between soil types in regard to production of oats and indicate the magnitude of increases in yields from complete fertilizer on the different soils.

The hay mixture seeded in the field tests consisted of timothy, red clover, alsike and alfalfa. To illustrate the different response of this crop from that of oats, to the treatments applied at the time of seeding, the data on hay yields for 1947 on one test on each of the four soil types will be discussed in relation to the yields of oats obtained in these tests in 1946.* From Table 8 it may be noted that on Castor silt loam and North Gower clay loam, where oats responded to phosphorus but not to potassium, appreciable increases in hay yields from phosphorus treatments and trends

* Sampling for hay yields was done by the Division of Forage Plants, Experimental Farms Service

towards small increases from potassium were obtained. On Uplands sand and Rubicon sand, where trends in favour of a slight response to phosphorus and to potassium by the oat crop occurred, the hay yields showed a response to each of these elements.

Nitrogen treatments which increased grain yields in all tests, resulted in lower hay yields. However, the 4-12-12 treatments produced appreciably higher yields than the checks. The higher yields of grain may have been responsible for the decreased hay yields. In an experiment conducted for four years by the Field Husbandry Division at Ottawa, in which oats were seeded at $1\frac{1}{2}$, 2, $2\frac{1}{2}$, and 3 bushels per acre, the yields of grain increased directly with rate from 72 bushels per acre at the lowest rate to 73, 80, and 85 bushels per acre for each of the respective rates. The yields of the first year succeeding alfalfa decreased directly with the increase in yield of oats, the decrease from the lowest rate to the highest being 280 lb. of dry matter.

Response of Oats and Alfalfa to N, P, and K in Greenhouse

In 1946, greenhouse studies to measure the response to fertilizer elements by grain and legumes on Carleton County soils were undertaken along the lines reported in 1945 (1). Tests on soil from three farms on each of ten soil types were conducted in 1946-47, and a similar set of tests on soil from different farms was carried out during 1947-48. A continuation of this work on soils from a sufficient number of fields distributed so as to represent each soil type will be very useful in evaluating chemical soil tests.

In Table 9, the responses of oats and alfalfa in the greenhouse to nitrogen, phosphorus and potassium, where each element was applied alone and in combination at the respective levels found in a 4-10-10 fertilizer at 400 lb. per acre, are given as averages for three farms on each soil type, sampled in 1946. The increases in yield from each element were calculated as illustrated in the discussion of field results. In general, oats responded to nitrogen and phosphorus but not to potassium, whereas alfalfa yields showed increases from phosphorus and potassium but decreases from nitrogen. In regard to the response to the minerals, there were variations between soil types. The oat crop showed no response to phosphorus on the Uplands sand, Rubicon sand and Kars gravelly sandy loam, and only slight response to this element on the Rideau clay. With the exception of the Rubicon sand (where soil from one farm gave different results), the alfalfa yields on these four soils showed less response to phosphorus than obtained on the other soils, there being no response on the Uplands sand. The alfalfa on Uplands sand, Rubicon sand and Kars gravelly sandy loam, responded to potassium more than to phosphorus, but on the other soils, phosphorus produced greater increases than potassium. The alfalfa on Rideau clay showed no response to potassium, and on the Grenville loam, Carp clay loam, and North Gower clay loam the response was slight. These trends were similar to those reported in the earlier paper (1) and in a general way followed the field observations where such were available.

Laboratory Results on Soil Samples

In texture, the soils under study varied from light sands to heavy clays. The lightest soils, Uplands and Rubicon, contained over 80 per cent sand; intermediate types such as Castor, Osgoode, Carp, North

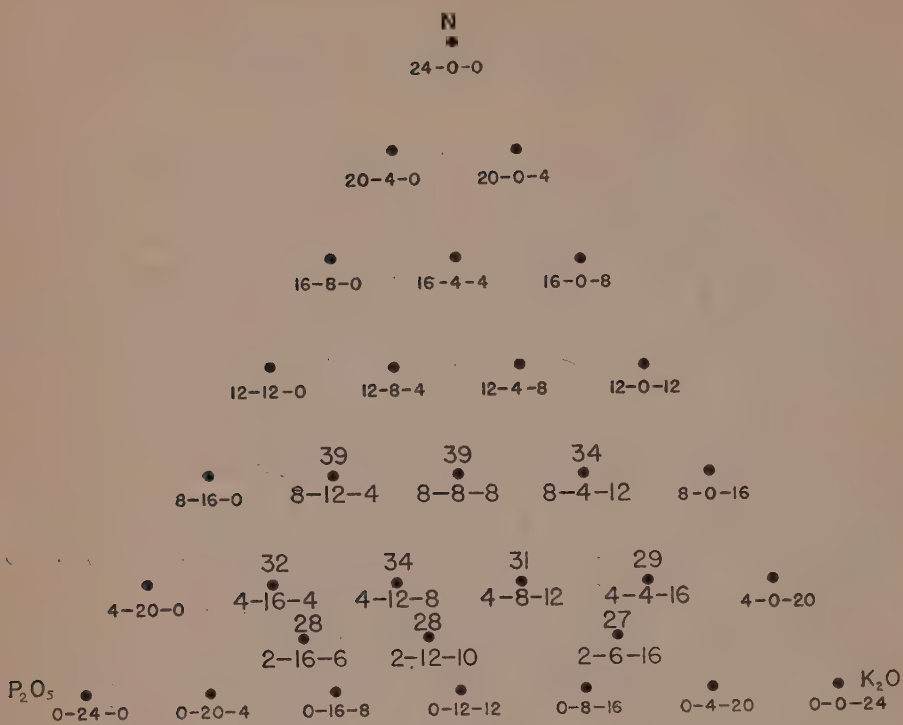

FIGURE 1. Yields of oats on Castor silt loam, receiving fertilizer ratios, located on Schreiner Triangle. Each yield is average in bushels per acre of grain, from rates of 200 and 400 lb. per acre of fertilizers. The yield for the check plots was 22 bu. per acre.

Gower, contained 40 per cent to 50 per cent silt; and the heaviest type, the Rideau, had over 40 per cent clay. The three samples from some types (Uplands, Osgoode, North Gower) were quite uniform in mechanical composition; those from certain other types (Kars, Manotick) were quite variable. This might be expected in the case of the last two soils on the basis of descriptions of their occurrence.

In reaction, the soils varied from moderately acid (pH 5.8) to strongly alkaline (pH 8.3). Of the 30 samples tested, 14 had pH values of 7.2 or over. All samples of Uplands and Rideau were acid; all samples of Grenville and North Gower were alkaline. In the case of most of the other types, the reactions of the samples ranged from acid through neutral to alkaline.

The organic matter content of these soils also showed considerable variation, as measured by nitrogen content and loss on ignition. The amount of nitrogen found ranged from 0.06 per cent to 0.37 per cent. The amount of organic matter is to a certain extent dependent on the system of farm management and might be expected to be higher in the soils from farms where considerable manure has been applied over a period of years. Nevertheless, there were some pronounced differences between soil types. The Uplands sand samples contained the lowest amounts whereas the highest levels were found in the Carp and North Gower soils.

The total phosphorus content varied from 0.11 to 0.33 per cent. P_2O_5 and there was considerable variation within each soil type. No analyses have yet been made to determine the amounts of phosphorus present in the organic form but this is information that should be obtained.

The amount of readily soluble phosphoric acid was determined by extraction with a solution of $KHSO_4$ at pH 2.0, as described by Lohse and Ruhnke (3). According to the standards given by the authors of the methods, not more than two of the samples examined would be considered deficient in this constituent; in fact, most of them would appear to be extremely well supplied. Nevertheless, as has been shown, response to applications of phosphorus has been obtained in the majority of cases.

Exchangeable bases were determined by extraction with neutral normal ammonium acetate solution. With the exception of the light textured soils, the samples examined were in general well supplied with exchangeable calcium and magnesium. Factors which affected the amounts of these bases were texture, reaction and organic matter content. The amounts of exchangeable potassium found were, on the whole, somewhat lower than might be expected. Two-thirds of the samples had less than 160 lb. K per acre in this form. The Rideau and Carp types contained the largest amounts; the Grenville appeared to be reasonably well supplied.

A considerable amount of information on the composition of samples from various soil types was presented in the Soil Survey Report (2). Further information obtained on samples used in greenhouse studies will supplement that previously obtained and, over a period of time, a very good picture of the variation between and within soil types in this area will be obtained.

FERTILIZER FORMULAE FOR OATS AND HAY CROPS

As a result of the experimental results discussed above, different ratios of nitrogen, phosphorus and potassium, based on the Schreiner Triangle (4) were applied in field tests in 1947, for oats seeded to hay on four soil types. The ratios, each of which contained the same total percentage of the three major elements, were randomized and replicated two and in some cases three times, except that they were applied at a different rate in each block, the rate effect being confounded with block effect. Since grain and hay crops respond differently, the most desirable ratios for grain seeded to hay cannot be assessed until hay yields are obtained. However, to illustrate the scheme of treatments, the average yields of grain from the two rates in a test on Castor silt loam are shown in Figure 1. In this test, the yields of grain increased with increase in per cent nitrogen in the ratios, and there was a slight trend in favour of ratios higher in phosphorus than potassium. The 8-12-4 and 8-8-8 ratios produced the highest yields, the increase over the check being 17 bushels per acre.

SUMMARY

In this paper, an attempt has been made to outline the approach to fertility studies on soil types that is being followed by the Divisions of Chemistry and Field Husbandry at Ottawa. The plan is to integrate field, greenhouse and laboratory studies very closely in order to obtain as complete a picture of the soils under investigation as possible. It is expected that the considerable amount of information so obtained will be most useful in extending the work to other soil types in other areas.

In the field, simple tests are laid out on private farms and yield data obtained thereon are carefully studied. The number of such tests which can be handled satisfactorily is limited. In the greenhouse, the investigation can be extended to include soil samples from many more individual farms and different farms can be sampled each year. With such a number of samples available for laboratory investigation, a considerable volume of data on the constitution of the soils in the county is being obtained. Thus soil composition, measurement of "available" constituents and response to fertilization can be correlated.

Soil samples from areas where field experiments are conducted are also brought into the greenhouse in an attempt to correlate response to fertilizer applications under these different conditions. In this connection, various points in greenhouse technique are being studied.

In general, from both field and greenhouse results, it appears that, on the Carleton County soils, grain responds to applications of nitrogen and phosphorus, whereas legumes respond to additions of phosphorus and potassium. It has been observed that a large grain yield may cause a reduced yield in the subsequent hay crop.

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THIRTY-FIVE YEARS OF WEATHER RECORDS AT SAINTE-ANNE-DE-LA-POCATIÈRE[1]

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[Received for publication June 21, 1948]

The importance of meteorological observations in agricultural research is widely recognized. Unfortunately the data accumulated through the years are not always readily available in a form most valuable to agriculturists. Since meteorological data have been recorded at the Experiment Station, Sainte-Anne-de-la-Pocatière, for a period of 35 years, it was decided that a study based on these data would be of value to various research workers.

The meteorological data have been tabulated and analysed statistically so as to bring out the characteristics of the climate. Statistical analysis of meteorological data was widely used by Hopkins (3, 4, 5, 6, 7, 8) and by others. Dingle (2) has recently emphasized the importance of using the frequency distribution as a supplement to the mean. The standard deviation was computed according to the method set forth by Snedecor (9). Since the data were obtained from a single station only, comparisons can be made by referring to Villeneuve (11).

LOCATION AND TOPOGRAPHY

The meteorological station of Sainte-Anne-de-la-Pocatière is in latitude 47° 22′ North and longitude 70° 22′ West of Greenwich, at 100 feet above sea level, and about two miles south of the St. Lawrence River. The Station is surrounded on the south side by a ridge of an elevation of some 300 feet.

The location and surroundings of the instrument shelter are shown in Figure 1. Free movement of air around the instruments might be restricted to some degree especially on the south and east sides. Maple trees on the north side may affect the movement of air during the summer.

PRECIPITATION

Precipitation is measured in hundredths of an inch twice daily from a rain gauge fixed on a wooden pillar. The precipitation data were computed and analysed so as to provide further information on the frequency, duration and intensity of rainfall, the importance of which has already been pointed out by Blumenstock (1).

The total monthly and annual precipitation for each year is given in Table 1. The total annual precipitation varies from 20.58 inches to 48.21 inches, with a mean of 36.66 inches. Variability from year to year is high, especially during the summer. The precipitation, however, is fairly well distributed through the months and seasons. A slightly greater amount of rainfall occurred during the summer, as shown in Figure 2. The wettest months were September and July. A gradual increase in the amount of

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TABLE 1.—CHARACTERISTICS OF THE MONTHLY PRECIPITATION, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

(Rain and melted snow, in inches)

Month	Mean	Range	Standard deviation
January	2.82	0.70 – 6.50	1.33
February	2.63	0.55 – 7.91	1.53
March	2.63	0.80 – 6.29	1.33
April	2.72	0.86 – 6.35	1.36
May	3.12	1.16 – 6.88	1.34
June	3.46	0.92 – 7.68	1.78
July	3.73	0.64 – 6.73	1.62
August	3.28	0.75 – 9.21	1.69
September	3.80	0.65 – 7.38	1.80
October	3.29	0.60 – 7.15	1.53
November	2.72	0.74 – 7.76	1.54
December	2.46	0.60 – 6.11	1.45
Year	36.66	20.58 – 48.21	6.00

TABLE 2.—CHARACTERISTICS OF THE MONTHLY SNOWFALL IN INCHES, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Mean	Range	Standard deviation
January	24.0	6.5 – 49.0	11.9
February	23.2	5.5 – 64.0	12.3
March	20.1	0.4 – 47.5	11.6
April	9.2	0.0 – 31.0	8.1
May	0.4	0.0 – 4.0	0.8
June	0.0	0.0 – 0.0	0.0
July	0.0	0.0 – 0.0	0.0
August	0.0	0.0 – 0.0	0.0
September	0.0	0.0 – 0.0	0.0
October	1.5	0.0 – 8.0	2.5
November	10.1	0.0 – 29.8	7.4
December	18.8	5.0 – 45.0	12.2
Year	107.2	50.0 – 205.5	32.9

precipitation can be observed in Figure 3 for the period 1913-47. This increase is perhaps due to the high of a long cycle, and not to a change in the climate.

Table 2 shows the annual and monthly amount of snowfall. The average annual snowfall is 107.2 inches ranging from 50.0 inches to 205.5 inches. Variability is low from year to year, if the amount of snow is converted into its water equivalent, one-tenth of an inch. The greatest amount of snowfall usually occurred in January and February. The average annual snowfall represents 28.2 per cent of the total precipitation. Snow cover does not always give as good a protection to perennial plants as the annual snowfall seems to indicate, on account of considerable drifting. Highly significant correlation (r = 0.57; D.F. = 33) was found between the precipitation of July and September. There was no relationship between any other months.

TABLE 3.—AVERAGE NUMBER OF RAINY DAYS PER MONTH, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Mean	Range	Standard deviation
April	9.7	3 – 17	3.5
May	10.5	4 – 16	3.2
June	11.0	3 – 18	3.4
July	11.5	3 – 17	3.2
August	10.1	4 – 18	3.4
September	10.6	4 – 20	3.7
October	11.2	5 – 19	3.7

The number of days per month in which a measurable amount (one-hundredth of an inch) of precipitation fell are recorded in Table 3 for each of the seven months from April to October. Differences between months are not great. Stormy days, that is days with rain or snow, are somewhat less numerous during the winter than during the summer as shown in Figure 4.

The frequency of occurrence of rainless and rainy periods of specified length are given in Tables 4 and 5, respectively. The procedure followed to calculate the random expected frequencies (headed expected) and to analyse the deviations of the observations from the expected values was the same as expounded by Hopkins (5). There was an excess of sequences

South West

North East

FIGURE 1. Position and surroundings of the instrument shelter when facing south, west, north and east.

TABLE 4.—FREQUENCY OF OCCURRENCE OF RAINLESS PERIODS OF SPECIFIED LENGTH, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Rainless period, days	April		May		June		July		August		September		October	
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
0	139	109.8	155	124.1	166	141.1	172	147.5	134	117.5	147	129.7	172	141.6
1	59	74.2	73	81.9	87	89.4	76	93.0	66	79.0	63	83.9	70	90.4
2	38	50.2	40	54.0	37	56.6	51	58.6	56	53.2	58	54.2	55	57.8
3	28	33.9	28	35.7	31	35.8	23	37.0	31	35.8	46	35.1	37	36.9
4	26	23.0	21	23.5	24	22.7	27	23.3	17	24.1	14	22.7	16	23.6
5	12	15.5	15	15.5	12	14.4	19	14.7	21	16.2	8	14.7	11	15.1
6	8	10.5	8	10.2	3	9.1	10	9.3	12	10.9	10	9.5	12	9.6
7	9	7.1	5	6.8	6	5.8	9	5.8	6	7.3	3	6.1	5	6.1
8	6	4.8	4	4.5	6	3.6	5	3.7	2	4.9	7	4.0	2	3.9
9	0	3.2	6	2.9	1	2.3	3	2.3	3	3.3	3	2.6	0	2.5
10	3	2.2	1	1.9	3	1.5	1	1.5	4	2.2	4	1.7	2	1.6
11	3	1.5	2	1.3	2	0.9	1	0.9	3	1.5	2	1.1	3	1.0
12	2	1.0	4	0.8	3	0.6	1	0.6	1	1.0	1	0.7	2	0.6
13	0	0.7	1	0.6	1	0.4	0	0.4	0	0.7	0	0.4	1	0.4
14	1	0.5	0	0.4	1	0.2	1	0.2	0	0.5	0	0.3	1	0.3
15	2	0.3	0	0.2	0	0.1	1	0.1	1	0.3	1	0.2	1	0.2
16	1	0.2	1	0.2	0	0.09			1	0.2			0	0.1
17	1	0.1	0	0.1	1	0.06			0	0.1			0	0.07
18	0	0.09	0	0.07	0	0.04			1	0.09			1	0.04
19	0	0.06	0	0.05	0	0.02							1	0.03
20	0	0.04	0	0.03	0	0.01								
21	0	0.03	0	0.02	0	0.01								
22	0	0.02	0	0.01	0	0.006								
23	0	0.01	0	0.009	0	0.004								
24	1	0.009	1	0.006	1	0.002								
χ^2	25.324†		19.344*		24.673†		18.155*		13.284		19.864*		20.301*	

* Exceeds 5 per cent point.
† Exceeds 1 per cent point.

TABLE 5.—FREQUENCY OF OCCURRENCE OF SEQUENCES OF DAYS WITH RAIN, SAINTE-ANNE-DE-LA-POCATIÈRE 1913-1947

Number of consecutive days with rain	April		May		June		July		August		September		October	
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
0	524	488.2	497	470.5	447	421.2	465	433.7	505	488.5	458	440.4	473	441.3
1	102	158.1	125	160.0	133	154.4	125	160.3	142	159.8	132	155.6	132	159.4
2	61	51.2	55	54.4	43	56.6	59	59.2	48	52.3	60	55.0	49	57.6
3	26	16.6	22	18.5	21	20.7	17	21.9	17	17.1	17	19.4	17	20.8
4	5	5.4	9	6.3	11	7.6	9	8.1	7	5.6	7	6.9	7	7.5
5	3	1.7	3	2.1	4	2.8	9	3.0	5	1.8	5	2.4	8	2.7
6	1	0.6	0	0.7	4	1.0	2	1.1	1	0.6	0	0.8	2	1.0
7			1	0.2	0	0.4	1	0.4	1	0.2	2	0.3	0	0.3
8			0	0.08	2	0.1	1	0.1					2	0.1
9			0	0.03									0	0.05
10			1	0.01									1	0.02
χ^2	16.973†		12.068*		14.838*		17.939†		6.996		6.279		14.853*	

* Exceeds 5 per cent.
† Exceeds 1 per cent.

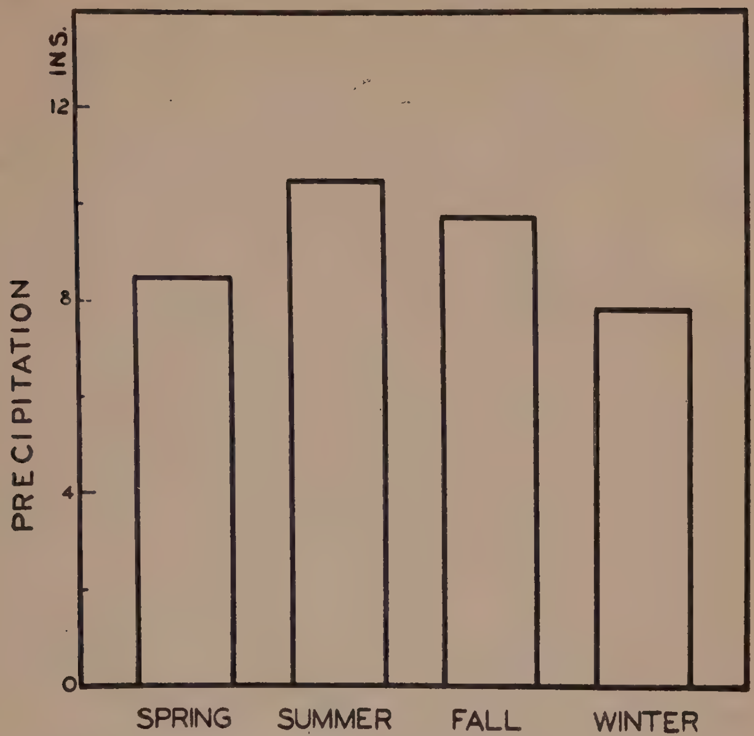

FIGURE 2. Seasonal distribution of the total precipitation in inches.

of zero dry days and of sequences of zero rainy days, and a deficiency of rainless periods of one to three days, similar to the condition found by Hopkins (5) in Western Canada. The statistical significance of the values χ^2 confirmed the previous findings of Hopkins (5) that rainy or rainless days do not in general occur entirely at random, but that the same kind of weather tends to persist over successive days. These statistics were used to estimate the expectation of rainless and rainy periods given in Table 6. Long periods of drought are expected less often in July and more often in April. Long rainy periods can be expected more often in October, June and July, and less often in April. These occurrences of rainy days tend to make haying operations somewhat more difficult.

The intensity of monthly rainfall expressed in daily rate is shown graphically in Figure 5 for each month from April to October. In general a little more than 50 per cent of the monthly rainfall fell at a rate of 0.01-0.20 inch per day. Rainfall intensity appears to be higher in September and lower in April. These data indicate that water run-off is more likely to occur in September, and possibly in July, than in other months, except possibly in the spring at the time when snow is melting.

Precipitation has another important bearing on the harvesting of crop for seed production. The amount of rainfall and the frequency of rainless periods seem to indicate that handling of crops for seed production should preferably be done in August. Periods of drought during the summer, and especially in August, decrease the productivity of pastures. The recurrence of these dry periods points out to the plant breeder the importance of drought resistance in clover improvement especially.

TABLE 6.—EXPECTED FREQUENCY OF OCCURRENCE OF RAINLESS AND RAINY PERIODS OF SPECIFIED LENGTH, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Length of periods, days	Expected frequency of occurrence, once in:						
	April	May	June	July	August	September	October
Rainless periods							
5 or more	0.7 yr.	0.7 yr.	0.9 yr.	0.7 yr.	0.6 yr.	0.9 yr.	0.8 yr.
10 or more	2.5	3.5	3	7	3	4	3
15 or more	7	17	17	35	12	35	12
20 or more	35	35	35	>35	>35	>35	>35
25 or more	>35	>35	>35	>35	>35	>35	>35
Rainy periods							
4 or more	4	2.5	1.7	1.6	2.5	2.5	1.7
5 or more	9	7	3.5	3	5	5	3
6 or more	35	17	6	9	17	17	7
7 or more	>35	17	17	17	35	17	12
8 or more	>35	35	17	35	>35	>35	12

TABLE 7.—CHARACTERISTICS OF THE MONTHLY MEAN TEMPERATURE, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Mean	Range	Standard deviation
January	10.8	0.9 – 21.1	4.2
February	12.5	2.9 – 18.8	3.8
March	23.7	13.0 – 31.8	4.3
April	36.3	29.5 – 43.2	3.4
May	49.1	40.6 – 54.4	3.3
June	59.2	52.6 – 65.5	2.6
July	65.0	59.7 – 72.4	2.7
August	62.8	56.7 – 69.0	2.9
September	54.3	46.0 – 59.3	3.0
October	44.1	37.9 – 50.7	2.8
November	30.7	21.7 – 36.8	3.6
December	15.9	6.8 – 27.3	4.2
Year	38.7	34.9 – 41.6	1.6

TEMPERATURE

The highest and lowest daily temperatures are read from a mercurial maximum thermometer and alcohol minimum thermometer respectively. The daily mean temperature is found by averaging the highest and lowest temperatures. The monthly mean temperature is the sum of these mean temperatures for a month divided by the number of days of the month.

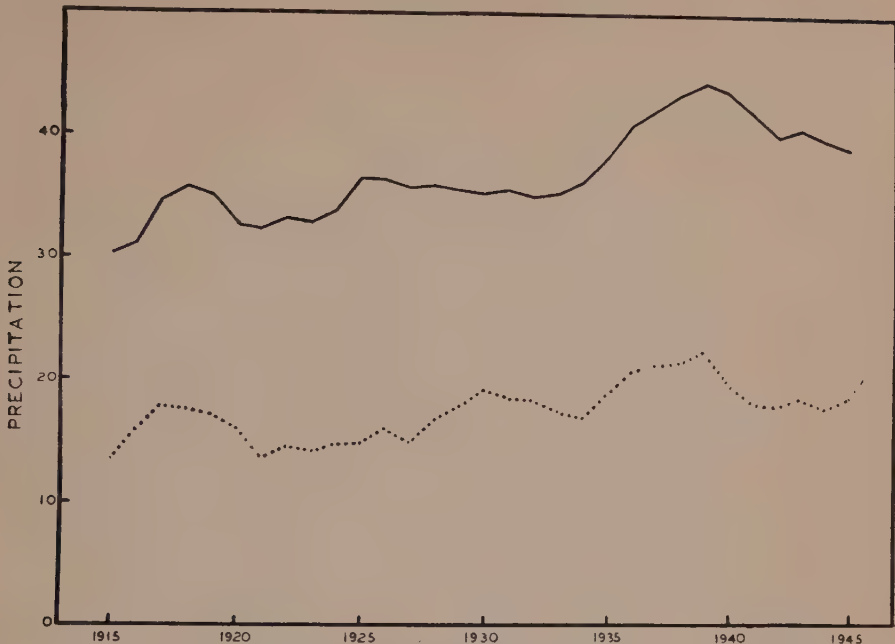

FIGURE 3. Five-year moving average of the total annual precipitation in inches *(solid line)* and of the amount of rainfall during the season of vegetation (May 1 to Sept. 30) *(dotted line)* from 1913 to 1947.

The monthly and annual mean temperatures are recorded in Table 7. The mean annual temperature is 38.7 degrees F. The variation from year to year of the annual mean temperature is rather small as indicated by a standard deviation of 1.6 degrees. The coldest month is January, the monthly mean temperature being 10.8 degrees F. July is the warmest month with a monthly mean temperature of 65 degrees F. The variation in the monthly mean temperatures is small during the summer and high during the winter, apparently as a consequence of the nearby large body of water which is frozen out during part of the winter. Similar features characterize the monthly mean maximum temperatures given in Table 8, and to some extent, the monthly mean minimum temperatures recorded in Table 9. The annual range of mean monthly temperature, which is the difference between the mean monthly temperature in July and the mean monthly temperature in January, is 54.2 degrees F.

Extreme monthly maximum and minimum temperatures are recorded in Tables 10 and 11, respectively. The lowest temperature recorded at Sainte-Anne-de-la-Pocatière since 1913 has been −33 degrees F. and the highest temperature 95 degrees F. The mean maximum temperature in July is 87.3 degrees F. and the mean minimum temperature in January is

TABLE 8.—CHARACTERISTICS OF THE MONTHLY MEAN MAXIMUM TEMPERATURE, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Mean	Range	Standard deviation
January	19.4	7.4 – 31.2	4.8
February	21.9	12.5 – 30.5	4.3
March	32.8	21.8 – 41.1	4.4
April	45.1	36.7 – 54.5	4.3
May	60.2	49.1 – 69.0	4.3
June	70.9	66.6 – 77.1	2.8
July	76.3	71.5 – 84.4	2.4
August	74.2	68.3 – 78.3	2.4
September	65.4	51.7 – 72.5	3.5
October	53.1	45.3 – 60.6	3.4
November	37.9	29.6 – 45.2	3.6
December	23.7	13.6 – 33.4	4.5
Year	48.4	44.1 – 51.8	1.8

TABLE 9.—CHARACTERISTICS OF THE MONTHLY MEAN MINIMUM TEMPERATURE, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Mean	Range	Standard deviation
January	2.6	−10.8 – 12.6	4.6
February	3.1	− 6.6 – 10.3	4.2
March	14.7	4.3 – 24.9	5.7
April	27.6	18.6 – 37.9	3.9
May	38.1	27.2 – 45.1	2.9
June	47.5	37.0 – 54.2	3.4
July	53.7	45.9 – 65.0	3.8
August	51.4	40.6 – 61.3	4.4
September	43.3	34.9 – 50.0	3.8
October	35.2	29.1 – 40.9	2.7
November	23.8	13.8 – 31.9	4.5
December	8.0	− 2.0 – 21.1	4.8
Year	29.0	23.9 – 31.8	2.0

TABLE 10.—CHARACTERISTICS OF THE EXTREME MONTHLY MAXIMUM TEMPERATURE, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Mean	Range	Standard deviation
January	39.4	28 – 50	5.5
February	37.2	12 – 46	6.2
March	48.4	38 – 61	6.5
April	63.8	50 – 82	8.7
May	78.8	69 – 88	5.3
June	85.4	78 – 95	4.4
July	87.3	82 – 94	3.2
August	85.5	80 – 93	3.4
September	80.8	72 – 89	4.5
October	70.1	58 – 80	5.4
November	57.6	43 – 70	7.2
December	41.1	32 – 55	5.6
Annual maxima	89.3	84 – 95	2.8

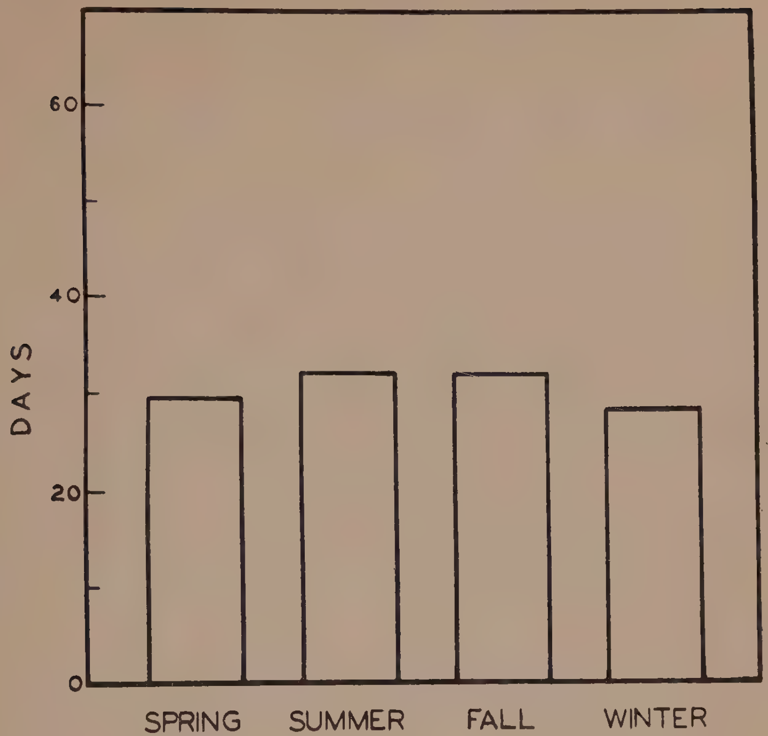

FIGURE 4. Mean seasonal frequency of stormy days.

−18.1 degrees F., thus giving a range of mean extreme temperature of 105.4 degrees. Temperatures below freezing-point have been recorded for every month of the year during the period 1913-1947.

Table 12 gives the monthly mean of the daily range of temperature. The daily range of temperature is higher during the summer months as a consequence from a greater solar radiation.

TABLE 11.—CHARACTERISTICS OF THE EXTREME MONTHLY MINIMUM TEMPERATURE, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Mean	Range	Standard deviation
January	−18.1	−32 – − 6	6.7
February	−15.5	−33 – − 4	7.3
March	− 5.6	−19 – 18	8.3
April	13.2	− 1 – 24	5.9
May	27.8	19 – 35	3.3
June	35.6	23 – 43	4.3
July	42.6	30 – 53	4.2
August	39.5	28 – 45	3.4
September	30.6	18 – 36	3.7
October	23.7	10 – 31	4.5
November	6.1	−10 – 22	7.4
December	−12.7	−27 – 1	7.4
Annual minima	−21.0	−33 – −10	5.7

TABLE 12.—CHARACTERISTICS OF THE MONTHLY MEAN OF DAILY RANGE OF TEMPERATURE SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Mean	Range	Standard deviation
January	17.3	5.8 – 29.1	5.0
February	18.8	12.4 – 32.7	3.4
March	17.7	3.5 – 29.8	4.6
April	17.5	6.2 – 29.8	4.5
May	22.1	14.1 – 31.9	3.5
June	23.3	18.0 – 31.2	3.3
July	22.6	14.8 – 31.8	3.4
August	22.8	15.4 – 33.3	4.2
September	22.1	11.3 – 31.2	4.2
October	17.8	13.6 – 26.0	2.9
November	14.6	9.3 – 28.3	3.9
December	15.7	9.2 – 30.0	3.8
Year	19.2	16.7 – 25.1	2.0

TABLE 13.—FROST DATA, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

	Mean	Range	Standard deviation
Last killing frost in spring	May 18	Apr. 27-June 4	10.3
First killing frost in fall	Sept. 28	Sept. 7-Oct. 30	10.0
Length of frost-free period in days	132.5	103 – 166	15.5

TABLE 14.—CHARACTERISTICS OF SUNSHINE RECORDS, SAINTE-ANNE-DE-LA-POCATIÈRE, 1913-1947

Month	Per cent of possible	Hours of sunshine		
		Mean	Range	Standard deviation
January	31.6	87.5	56.5 – 116.3	15.7
February	38.0	109.4	61.0 – 159.4	21.6
March	38.7	142.1	105.6 – 213.2	25.9
April	41.1	168.8	112.2 – 236.5	33.4
May	44.3	207.4	141.6 – 287.1	38.8
June	44.4	211.1	134.1 – 275.2	37.2
July	52.2	250.2	170.2 – 293.8	26.8
August	51.9	227.9	175.3 – 278.0	29.8
September	42.2	157.9	87.3 – 213.1	32.4
October	33.7	112.8	61.4 – 174.5	28.1
November	25.5	71.6	36.2 – 109.3	19.8
December	26.6	69.9	44.5 – 103.0	15.6
Year	40.8	1816.6	1489.1 – 2030.7	134.7

Temperature data indicate that Sainte-Anne-de-la-Pocatière shows a slight tendency towards a marine climate. The equalizing effect on temperature of the St. Lawrence River is apparent principally during the summer.

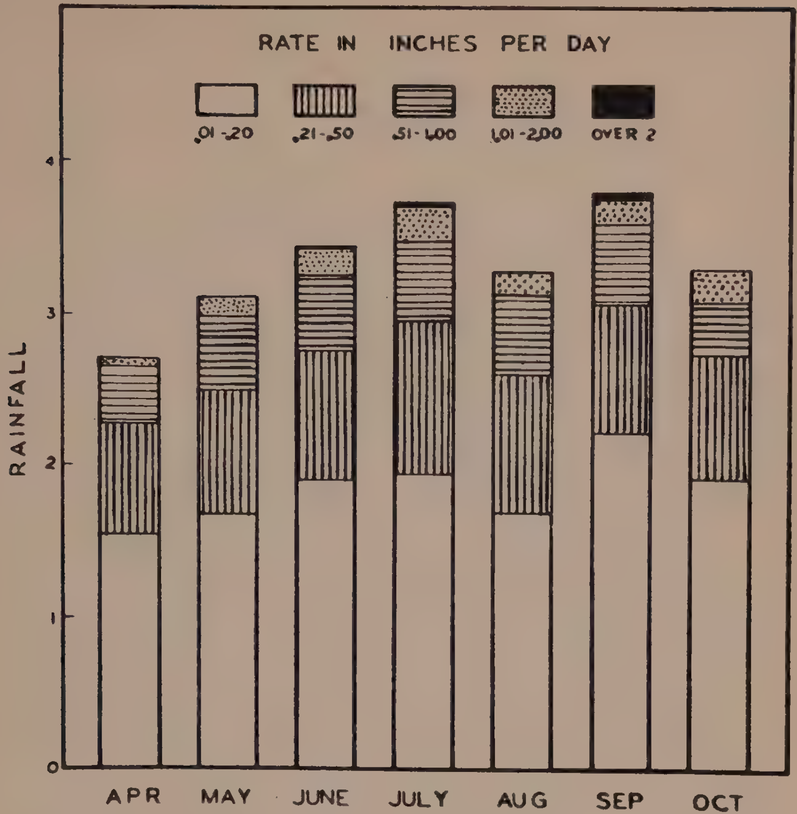

FIGURE 5. Rainfall amounts in inches falling at specified intensities, showing monthly variation from April to October, 1913-1947.

The frost-free period is the average number of days between the last frost in the spring and the first frost in the fall. Temperature of 32 degrees F. was used as a criterion of killing frost. Data relative to the length of the growing season are summarized in Table 13. The average length of the frost-free period is 132.5 days with a standard deviation of 15.5 days. The shortest season had 103 days and the longest one 166 days.

TABLE 15.—CHARACTERISTICS OF THE MONTHLY RATE OF EVAPORATION IN INCHES FROM WRIGHT EVAPORIMETER AND CONVERTED IN LIVINGSTON UNITS, SAINTE-ANNE-DE-LA-POCATIÈRE, 1938-1947

Month	Mean	Range	Standard deviation
April	2.04	1.46 – 2.91	0.50
May	6.02	4.14 – 7.92	1.15
June	6.65	4.94 – 9.22	1.29
July	7.10	6.25 – 8.09	0.69
August	6.32	4.66 – 8.15	1.28
September	5.11	4.03 – 7.22	1.11
October	2.20	1.32 – 2.96	0.48
Total	35.24	30.90 – 40.59	3.00

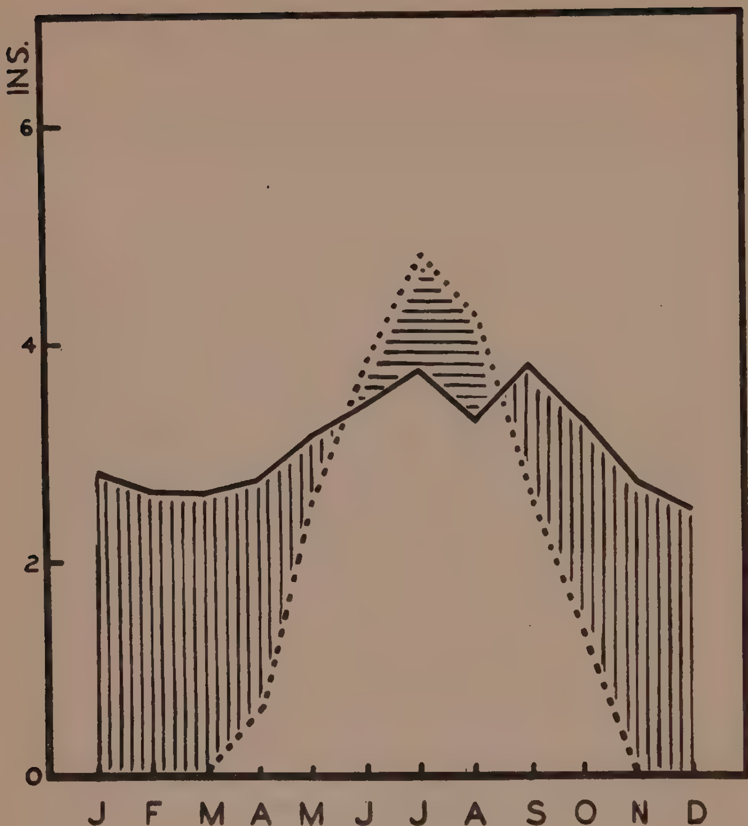

FIGURE 6. March of precipitation (*solid line*) and potential evapotranspiration (*dotted line*) at Sainte-Anne-de-la-Pocatière.

SUNSHINE

Sunshine records in Table 14 show that July has the most hours of sunshine and December the least. Year-to-year variation is the greatest for the month of May and the smallest for the month of December. The average number of hours of sunshine for the year is 1816.6 with a standard deviation of 134.7 hours. This represents 40.8 per cent of possible sunshine. The percentage of possible sunshine is about 32.0 during the winter months and rises to a value of 49.5 for the summer months.

EVAPORATION

The rate of evaporation, as measured by the Wright evaporimeter and reduced to Livingston units, is given in Table 15, from about April 15 to October 15. The length of records covers only a few years. The highest rate of evaporation occurs in July with a low standard deviation.

Thornthwaite (10) has recently discussed an important climatic element called "evapotranspiration" which is the combined evaporation from the soil surface and transpiration from plants. "Potential evapotranspiration" is the amount of water which would transpire and evaporate if it were available. The computation of the "potential evapotranspira-

TABLE 16.—CHARACTERISTICS OF THE HOURLY WIND VELOCITY, SAINTE-ANNE-DE-LA-POCATIÈRE, 1936-1947

Month	Mean	Range	Standard deviation
January	7.4	3 – 13	2.9
February	6.0	4 – 12	2.3
March	5.9	3 – 11	2.3
April	5.5	2 – 9	1.9
May	5.3	3 – 8	1.5
June	4.5	2 – 7	1.5
July	4.5	2 – 6	1.5
August	3.9	3 – 6	0.9
September	4.2	2 – 7	1.8
October	5.9	3 – 9	2.4
November	4.9	2 – 8	2.0
December	6.2	3 – 9	1.8
Year	5.3	3 – 7	1.3

TABLE 17.—PER CENT FREQUENCY OF WINDS FROM EIGHT DIRECTIONS FOR THE VARIOUS MONTHS OF THE YEAR, SAINTE-ANNE-DE-LA-POCATIÈRE, 1918-1947

Month	Percentage of winds from:							
	N.	S.	E.	W.	NE.	NW.	SE.	SW.
January	5	7	14	37	10	9	4	14
February	4	5	16	37	13	8	3	14
March	6	5	12	33	17	8	3	16
April	9	4	14	25	24	8	2	14
May	9	2	14	30	24	7	2	12
June	6	3	12	34	19	9	1	16
July	6	3	8	41	12	11	1	18
August	5	4	8	45	12	11	1	14
September	8	5	13	35	12	9	1	17
October	7	3	9	33	15	12	3	18
November	6	5	13	36	17	8	3	12
December	6	6	11	35	13	10	3	16
Year	7	4	12	35	16	9	2	15

tion" has been made possible by a formula developed by Thornthwaite (10), when the mean monthly value of temperature is available, and the latitude of the station is known. The monthly value of "potential evapotranspiration" was computed for the present station and is graphically shown in Figure 6 in comparison with the precipitation. The annual "potential evapotranspiration" is 19.7 inches. It rises to a maximum of 4.8 inches in July. During the summer months the water deficiency is about 2.4 inches on the average. The climate is dry during these months, because water need is greater than precipitation. However, water stored in soils may decrease to some extent the dryness of this period when rainfall is deficient. The climate is wet the rest of the year, with a water surplus of 16.9 inches which either runs off or is being stored in the soil.

Precipitation alone does not always give an exact picture of the climate in relation to plant need. Examination of rainfall data in Figure 6 indicates that April is relatively dry and July relatively moist. But when precipitation is compared with the "potential evapotranspiration," April becomes wet and July dry.

WIND

Wind velocity is observed twice daily, 8.00 a.m., and 6.00 p.m. The present observations were converted from the Beaufort scale into miles per hour.

Hourly wind velocity is given in Table 16 for the period 1936-47. The region is characterized by constant winds. There are very few calm days. The wind velocity is especially high during the winter months. Winds from the west are dominant for every month of the year. The frequency distribution of the wind direction is shown in Table 17.

SUMMARY

Thirty-five years of weather observations have been computed at Sainte-Anne-de-la-Pocatière. The data were analysed by means of the standard deviation. Precipitation, temperature, length of frost-free period, sunshine, evaporation and wind are recorded and discussed.

ACKNOWLEDGMENTS

The writers wish to acknowledge deep appreciation to P. O. Ripley, Dominion Field Husbandman, Central Experimental Farm, Ottawa, A. N. Dingle, Assistant Professor of Physics, Ohio State University, and G. O. Villeneuve, Director of the Quebec Bureau of Meteorology for reading the manuscript and offering helpful criticisms. The data used herein were obtained directly from the original meteorological record sheets of the Experimental Station, Sainte-Anne-de-la-Pocatière, by kind permission of J. R. Pelletier, Superintendent.

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SOME FACTORS AFFECTING APPLE YIELDS IN THE OKANAGAN VALLEY

V. AVAILABLE P, K AND Ca IN THE SOIL[1]

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[Received for publication June 19, 1948]

This paper is the fifth in a series reporting the findings of an investigation started in 1937 into the effects of certain factors on apple tree performance in the Okanagan Valley in British Columbia. In this investigation, two major approaches have been used in studying the nutrient status of the soil. The first has been soil analysis, and the second tissue analysis. In this paper, an initial report is made on the P, K and Ca status of the soil as determined by soil analysis only. The results obtained from tissue analysis will be discussed in a subsequent paper.

Three phases of the soil analysis work will be presented, as follows: *first*, analyses of soil samples from apple fertilizer plots; *second*, soil analyses from areas of known P and K deficiencies; and *third*, correlations between soil analyses and apple tree performance. Each of these will be discussed in turn.

PROCEDURE

Sampling the Soil

The procedure used in sampling the soil has already been described (9). Briefly, the method used was to take 10 samples from around an individual tree at each of three depths (0-8 inches, 8-24 inches, and 24-60 inches), and to composite the samples from each depth. In many cases, a mixture of coarse sand and gravel was encountered before a depth of 60 inches was reached; and in such cases sampling was discontinued at or near the top of the gravel. All samples were taken at distances of 4 to 10 feet from the trunk of the tree. In subsequent work (10), it was found that selecting soil samples from near the trunk of the tree in this manner does not provide a true picture of the nutrient status of the whole soil area. In spite of this, the information gained in this investigation has proved of considerable value.

In the laboratory, the soil samples were allowed to air dry in open cans. They were then screened through a 3 mm. sieve, and the gravel and stones were discarded. Each sample was thoroughly mixed, and stored in covered No. 10 tin cans.

Extracting the Soil

The method used for extracting the soil samples was a modification of the CO_2 extraction procedure developed by McGeorge and his co-workers in Arizona (3, 4, 5). Their final procedure (4) was to add 250 ml. of distilled water to 50 gm. of soil, pass CO_2 through the mixture with occasional shaking for 15 minutes, and filter. The method used in this investigation was as follows:

(*a*) Mix soil and distilled water in the ratio of 1 : 2. The reason for using this ratio was that in the Okanagan Valley the water added to the soil annually by precipitation and irrigation is approximately twice the

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weight of the soil in the 18-inch area (6 to 24 inch depth) of greatest tree root concentration. With most of the samples, the amounts used were 800 gm. of soil and 1600 ml. of water, but with the samples from areas of known deficiencies the amounts used were 100 gm. of soil and 200 ml. of water.

(*b*) Pass CO_2 through the mixture in a steady stream for one hour, with occasional shaking. Let stand over-night under an atmosphere of CO_2.

(*c*) Shake again and filter. The larger samples were filtered by suction through Livingston baked clay atmometers, the smaller ones without suction through Whatman No. 5 filter paper.

P Determination

A modification of the usual Deniges molybdate method (2, 7) was used for determining P. Briefly, the procedure was as follows: Place 15 ml. of soil extract in a test tube. Add 2-6 dinitrophenol indicator and adjust the pH to a faint yellow and then barely to a bright yellow. Make up to 20 ml. with distilled water. Add 1 ml. of 15 per cent sodium bisulphite (Na HSO_3) solution, mix by inversion, and let stand over-night. Place in a bath of running tap water for 15 minutes. Add 1 ml. of ammonium molybdate solution, made by dissolving 10 gm. of ammonium molybdate in 200 ml. of water and adding this to 600 ml. of 25 per cent sulphuric acid. Mix by inversion. Add 1 ml. of aminonaphtholsulfonic acid solution, made by dissolving 0.5 gm. of 1-2-4 aminonaphtholsulfonic acid powder in a mixture of 400 ml. of 15 per cent sodium bisulphite and 30 ml. of 20 per cent sodium sulphite (2). Mix by inversion and replace in water bath. In 5 hours, take a colorimeter reading using a red filter. A Klett-Summerson colorimeter was used. Results were expressed as parts of P per million parts of dry weight of soil.

Standards containing known amounts of P were run at the same time and in the same manner as the unknowns. Colorimeter readings charted against P contents gave straight-line trends. It was therefore necessary to run standards containing only two concentrations of P.

This procedure was slow, but required only a small amount of operating time and gave good accuracy. All determinations were made in duplicate. By using Na HSO_3 as a reducing agent, no difficulty was encountered from arsenate, ferric, or nitrate ions. Adjustment to a constant pH was found to be necessary for accuracy. The method used gave a deep blue coloration when the colorimeter reading was taken. A constant temperature was also found to be necessary for accuracy. Somewhat greater accuracy was obtained by keeping the mixtures at tap water temperatures (20 to 25° C.) for 5 hours than by keeping them on a steam bath for $\frac{1}{2}$ or 1 hour.

K Determination

A modification of the usual sodium cobaltinitrite procedure, as adapted to turbidimetric use (1, 6), was developed. The procedure was as follows: Place 2 ml. of the soil extract in a test tube. With soils very low in K, more than this amount is used, and with soils very high in K, less than 2 ml. is used. Add 1 ml. of 40 per cent formaldehyde. Make up

to 5 ml. with distilled water. Place in bath of running water, at a temperature of not over 20° C. Also place in the bath a test tube containing 10 ml. of 95 per cent ethyl alcohol and another containing 5 ml. of sodium cobaltinitrite reagent. (This latter is made by dissolving 100 gm. of sodium cobaltinitrite, 400 gm. of sodium nitrite, and 400 gm. of hydrated sodium acetate in water and making up to 2000 ml.). Test tubes of 1 inch diameter are preferable to smaller tubes for this purpose. After at least 10 minutes of cooling in the bath, pour the mixture containing the unknown quickly and steadily into the sodium cobaltinitrite reagent. Pour back and forth twice, add the alcohol, insert stopper and shake. Return to water bath for 10 minutes and take a colorimeter reading, using a red filter. Results are expressed as parts of K per million parts of dry weight of soil.

Standards containing known amounts of K were run at the same time and in the same manner as the unknowns. Colorimeter readings charted against K contents gave a curved line, and it was therefore necessary to run a whole series of standards with each lot of unknowns.

This method was quite rapid, but was not quite as accurate as desired. The chief cause of variability was found to be in the mixing. By adopting a standard method of mixing and adhering strictly to it, much greater accuracy was attained. Even then, duplicates did not always agree within 10 per cent. When this occurred, further determinations were made until agreement was within 10 per cent. The sodium cobaltinitrite reagent gave just as satisfactory results when it contained sodium acetate as when it contained acetic acid, and there was no difficulty from acetic acid fumes. Because of the high buffering capacity of the reagents, it was not found necessary to make pH adjustments. A constant temperature at or below 20° C., however, was found to be essential for best results. The formaldehyde served to eliminate the effects of the ammonium ion. The alcohol served to bring about rapid formation of turbidity. The turbidity developed was not constant, so that it was necessary to take colorimeter readings at a constant time after adding the reagents.

Ca Determination

A modification of the Peech and English (6) method was used. The modifications were, briefly, as follows: (*a*) The CO_2 extract was used for analysis, as with P and K. (*b*) Bromphenol blue indicator was used to bring all unknowns to a pH of approximately 4.8 before the reagents were added. (*c*) Unknown solutions and reagents were kept at a constant temperature in running tap water. Results were expressed as parts of Ca per million parts of dry weight of soil.

For the most part, this method gave excellent results. All tests were run in duplicate. Where duplicates differed from one another by more than 10 per cent (which seldom occurred), further determinations were made.

Free Lime Determination

The method has already been described (9). It consists of adding hydrochloric acid to a soil-and-water mixture in a 100-ml. graduated cylinder and noting the height of rise of the bubbles. Results are only approximate.

Method of Expressing Results

All results obtained were corrected for percentage of gravel, on the assumption that the nutrient content of the gravel was zero. For example, if the original soil contained 50 per cent of gravel that was discarded on screening, and the screened soil contained 2.0 p.p.m. P, then the corrected figure for P would be 1.0 p.p.m. All nutrient contents were expressed in parts per million of the dry weight of the soil.

In addition to the concentration of each nutrient at each depth in the soil, it was desired to express in some manner the total quantity present in the profile as a whole. This was done in terms of pounds per acre of P, K and Ca, respectively. In transferring parts per million to pounds per acre, it was assumed that an acre foot of soil weighs 4,000,000 pounds. When both surface soils and subsoils were included, this figure was not far from the average for the types of soil encountered in this investigation. The depth of sampling in each case was assumed to be the depth of the profile, that is, to a depth of five feet unless the underlying horizon of stones and coarse sand was encountered above that depth.

FERTILIZER PLOTS

A large number of fertilizer tests have been run with apple trees in the Okanagan Valley. Although by 1940 some of these tests had been conducted for periods of ten years or more, no beneficial effects of P or K had yet been observed. Two of these series of plots are still under test, and still show no measurable beneficial effects of P or K fertilizers (11). Soil samples were collected from three series of the plots in the spring of 1940, and were analysed for P, K, Ca and free lime. These three series included the fertilizer plots started in the Barnard orchard in Penticton in 1930, the plots started in the Butler orchard in East Kelowna in 1928, and the plots started in the Willis orchard in Rutland in 1932. Some of the results have already been published (11); however, they are presented again in Table 1. The data in this table serve as a basis for comparison with data obtained from soils from other parts of the Okanagan Valley, which will be presented below.

It is of interest to note that both the P content and K content tended to decrease with depth. The same was true with the Ca content where no free lime was present. Where free lime was present in the subsoil, however, the Ca content was much higher there than in the surface soil. It will be noted that the P and K contents of the surface 8 inches of Plot P1 were lower than in Plots P2 to P4, while the reverse was true with Ca. The reason for this was that the original surface soil had mostly been scraped off Plot P1 in levelling operations before planting.

The most important data in Table 1 are the contents of P and K in the untreated and N-only plots. With P, the lowest content in the surface 8 inches was 0.8 p.p.m. in Plots P1 and B30. With K, the lowest content in the surface 8 inches was 64 p.p.m. in Plot B30. It can safely be assumed, then, that by the methods of analysis used these quantities are above the deficiency ranges. It is of interest also to note that the lowest content of Ca in the surface 8 inches was 74 p.p.m. in Plot B30.

TABLE 1.—P, K AND CA CONTENTS OF FERTILIZER PLOT SOILS

Plot No.	Treatment	Soil depth	pH	P content	K content	Ca content	Free lime
		in.		p.p.m.	p.p.m.	p.p.m.	%
Barnard Plots							
P1	O*	0-8	7.61	0.8	69	485	1.4
		8-24	8.19	0.2	48	559	5.2
		24-60	8.29	0.2	49	469	2.8
P2	N	0-8	6.85	3.3	105	187	0.0
		8-24	7.88	1.2	57	455	2.1
		24-60	8.08	0.4	51	484	5.2
P3	NP	0-8	6.28	11.9	81	183	0.0
		8-24	7.47	1.1	51	447	0.1
		24-60	8.13	0.6	46	565	3.9
P4	NPK	0-8	6.36	10.2	132	145	0.0
		8-24	7.75	1.2	56	542	0.6
		24-60	8.13	0.3	52	590	5.4
Butler Plots							
K11	NP	0-8	6.46	10.1	79	157	0.0
		8-24	6.36	0.5	20	27	0.0
K12	NPK1	0-8	5.87	8.8	105	82	0.0
		8-24	6.34	0.5	20	24	0.0
K13	NPK2	0-8	6.30	8.2	110	106	0.0
		8-24	6.34	1.1	33	25	0.0
K14	NPK3	0-8	5.99	8.9	180	88	0.0
		8-24	6.36	0.8	26	33	0.0
K15	O	0-8	6.66	2.0	74	98	0.0
		8-24	6.46	0.2	19	20	0.0
K46	N	0-8	6.27	1.6	80	94	0.0
		8-24	6.51	0.2	14	20	0.0
K51	NP	0-8	5.67	8.4	80	96	0.0
		8-24	6.15	0.5	25	21	0.0
Willis Plots							
B29	O	0-8	6.93	1.4	68	106	0.0
		8-30	7.10	0.3	35	51	0.0
B30	N	0-8	6.21	0.8	64	74	0.0
		8-27	6.68	0.3	33	59	0.0
B31	NP	0-8	5.82	16.4	87	111	0.0
		8-27	6.78	2.6	36	80	0.0

* O—no treatment; N—nitrogen; P—phosphate; K—potash.

SOILS WITH PROVEN P AND K DEFICIENCIES

As already stated, no cases of proven P or K deficiencies have yet been encountered with tree fruits in the southern interior of British Columbia. This has made it very difficult to set up any standards of sufficiency or deficiency. Information of some value has been obtained from the fertilizer plots, but it has been impossible from this alone to determine the range of values for either element that can be considered as falling at the "critical"

points, between sufficiency and deficiency. In order to gain this information, soil samples with proven P or K deficiencies were obtained in 1943 from other tree fruit areas. The sources from which these samples were obtained are listed in Tables 2 and 3. Also shown in these tables are the depths of sampling, the crop concerned, and the sufficiency or deficiency of P or K for this crop. Where the depth is not stated, it can be assumed that it was approximately 0 to 6 inches.

These soil samples were extracted and analysed by the same procedures as used on the Okanagan Valley samples. The pH and the P and K contents are summarized in Tables 2 and 3.

No one specified content of "available" P or K in the soil can be accepted as representing the dividing line between sufficiency and deficiency, i.e. the "critical point". The position of this critical point is affected by a number of other factors, such as the following: (*a*) the depth of the soil, (*b*) the type of crop, (*c*) the soil moisture content, (*d*) the presence of other limiting factors. Instead of a "critical point," therefore, the best that can be anticipated by any method of analysis is a "doubtful range". This is especially true where only the surface soil is being analysed. In a previous paper (10), the author has shown the importance of the subsoil as well.

Some overlapping of "sufficiency" and "deficiency" can be found in Tables 2 and 3. Prunes in California did not respond to P fertilizer with only 0.14 p.p.m. P in the soil, while vegetables in Washington responded with as high as 0.88 p.p.m. P in the soil. Tree fruits in Ontario showed no need for K fertilizer with only 33 p.p.m. K present in the soil, while tree fruits in Pennsylvania responded to K fertilizer with 44 p.p.m. K present. On the whole, however, the results were reasonably consistent. All responses obtained with P fertilizer on tree fruits were with 0.23 p.p.m. or less of P in the soil; and all responses obtained with K fertilizer were with 44 p.p.m. or less of K present.

TABLE 2.—DATA ON SOILS FROM AREAS DEFICIENT IN P

Sample No.	Source*	Crop concerned	pH	P content
				p.p.m.
U1	Aitken clay loam, Ore.	Not stated	5.38	0.13
U2	Aitken silty clay loam, Ore.	Not stated	5.31	0.09
U3	Melbourne silty clay loam, Ore.	Not stated	5.29	0.16
U5	Salkum clay loam, Ore.	Not stated	4.58	0.09
U6	Prosser, Wash.	Vegetables	6.92	0.88
U7	Prosser, Wash.	Vegetables	6.20	2.70**
U8	Prosser, Wash.	Vegetables	6.14	0.40
U10	Aitken clay loam, Calif.	Annuals but not prunes	5.98	0.14
U11	Norfolk sandy loam, Miss.	Tree fruits	5.07	0.05
U13	Ontario	Tree fruits	6.17	0.23
U14	Ontario	Tree fruits	6.29	0.21
U15	Ontario	Tree fruits	5.26	0.05
U16	Ontario	Tree fruits	5.57	0.16
U17	Ontario	Tree fruits	6.41	2.20**
U18	Ontario	Tree fruits	6.47	2.05**
U21	Quebec	Vegetables	5.21	0.27
U23	Merville loam, B.C.	General	5.30	0.05
U24	Keating sandy loam, B.C.	General	5.23	0.72**

* As far as known, all of these samples were obtained at a depth of 0 to 6 inches.
** P not deficient in these cases. P was reported to be deficient in all samples not thus marked.

TABLE 3.—DATA ON SOILS FROM AREAS DEFICIENT IN K

Sample No.	Source	Crop concerned	Depth*	pH	K content
			in.		p.p.m.
U4	Polk clay loam, Ore.			5.11	7
U9	Pinole soil series, Calif.	Tree fruits	0-12	5.59	8
U13	Ontario	Tree fruits		6.17	9
U14	Ontario	Tree fruits		6.29	15
U15	Ontario	Tree fruits		5.26	8
U16	Ontario	Tree fruits		5.57	8
U17	Ontario	Tree fruits		6.41	13
U18	Ontario	Tree fruits		6.47	33**
U19	Ontario	Tree fruits		5.95	28
U20	Ontario	Tree fruits		7.19	7
U25a	Massachusetts	Tree fruits	0-2	4.78	85**
U25b			2-8	4.77	40
U25c			8-20	5.10	31
U26a	Massachusetts	Tree fruits	0-8	5.91	5
U26b			8-20	5.37	3
U27a	Massachusetts	Tree fruits	0-8	4.68	34**
U27b			8-20	4.93	28
U28a	Massachusetts	Tree fruits	0-8	4.37	9
U28b			8-20	4.91	8
U31	Sassafras gravelly loam, Md.	Tree fruits	0-10	5.84	5
U32	Bath gravelly silt loam, N.Y.	Vegetables		5.06	4
U35	New York	Tree fruits	0-8	5.92	7
U36	New York	Tree fruits	0-8	5.01	68**
U37	New York	Tree fruits	0-8	5.50	208**
U38	Ashe-Porters series, Pa.	Tree fruits		6.17	26
U39	Penn-Porters mixture, Pa.	Tree fruits		6.39	10
U40	Chester-Manor series, Pa.	Tree fruits		5.01	44
U41a	Florida	Tung	0-6	5.23	10
U41b			6-12	5.11	4
U43a	Florida	Tung	0-6	5.37	8
U43b			6-12	5.16	4

* Where the depth is not stated, it is assumed that it is approximately 0-6 inches.
** K not deficient in these cases. K was reported to be deficient in all soils not thus marked.

The question arises as to whether the values of 0.23 p.p.m. P and 44 p.p.m. K can be accepted as "critical values". In other words, should fertilizers be recommended wherever the surface soil contains less than these values, but not where it contains more? This would not be safe for general application even to just tree fruits. It is quite possible that under certain conditions responses to P or K fertilizer could be obtained with even higher amounts than these present in the soil. In spite of the fact that in some cases no response has been obtained with less than 0.23 p.p.m. P or 44 p.p.m. K present in the soil, it appears safer to set tentative critical values at higher points than these. The values in use at present in this laboratory are 0.40 p.p.m. P and 50 p.p.m. K in the surface soil. It is assumed that when the soil is getting this low in P or K it is good insurance to apply the required fertilizer in order to prevent P or K deficiency. These figures refer of course to only the surface soil. Where cumulative quantities can be determined for the whole profile, it appears preferable to base the critical values on these rather than on the amounts in the surface soil only.

It is of interest to compare these critical values with the P and K contents in the fertilizer plots. The lowest values obtained in the surface soil of the fertilizer plots were 0.80 p.p.m. P and 64 p.p.m. K.

SOIL ANALYSES FROM McINTOSH PLOTS

In 1937, 73 plots of McIntosh trees were established in the Okanagan Valley, mostly in grower-owned orchards. The fertilizer plots already described in this paper were included. Records of yield and vigour were taken for a period of six years, and soil samples were collected in 1940. The methods of plot selection and recording, and the tree records obtained, have been outlined in the first paper (8) of this series; while the methods of soil sampling and some of the soils data obtained have been presented in the second paper (9) of the series.

Some of the plots received P fertilizer; some K fertilizer; some both; some neither. A careful examination was made of the 400 trees in the plots, but no leaf symptoms of P, K or Ca deficiency were observed. It has therefore been assumed that any deficiencies of these three elements which might have occurred in these plots could be of a minor nature only.

The P, K and Ca analyses of the soils from these plots are summarized in Table 4 in the Appendix. As added information on these soils, there are also included in this table the moisture-holding capacity per foot of soil, the pH, and the content of free lime.

Effects of Soil Depth

The data in Table 4 reveal an effect of soil depth similar to that noted in the special fertilizer plots. Where no P fertilizer had been applied, the P content in the 8-24 inch depth was one-third or less of that in the 0-8 inch depth. Usually the P content below 24 inches was somewhat less than at 8-24 inches. Where P fertilizers had been applied, the discrepancy was much greater between the 0-8 inch depth and the 8-24 inch depth. It appeared that very little of the P applied as fertilizer had moved down below the 8 inch level. With K the effects of depth were somewhat similar, except that the differences between the 0-8 inch depth and the 8-24 inch depth were not so marked.

With Ca, the effects of depth of soil depended primarily on the texture and on the depth of the profile. With sandy, shallow soils, the Ca content lessened with depth, in a manner similar to P and K. With deep, heavy soils, however, the reverse held true; that is, the Ca content in the subsoil was usually much higher than in the surface soil. This was due primarily to the presence of free lime in the lower horizons of the deep silts and clays. The depth at which the lime was encountered was usually about 15 to 20 inches, though some exceptions occurred. Where surface soil had been removed by erosion or by levelling operations (e.g. Plot P1), lime was found at or close to the surface. In deep sandy loams, on the other hand, the lime did not appear above a depth of 30 inches. In all cases, once lime was encountered it continued to the full depth of examination, which was usually 60 inches with the silt and clay soils. As noted in a previous paper (9), the high lime and high Ca contents in these soils were not associated with a hardpan condition.

Effects of Soil Texture

In the surface soil, the effects of texture were masked to some extent by fertilizer treatments. This was especially true with P and K. Indications are that the effects of fertilizing were negligible below a depth of 8 inches.

Evidence of the effects of soil texture has been obtained by correlating each element with various measurements of texture. Some of the correlations obtained with P were as follows:

(*a*) *In 0-8 inch samples*

Between p.p.m. P and per cent clay	−0.060
Between p.p.m. P and per cent colloid	−0.045
Between p.p.m. P and moisture-holding capacity	+0.011

(*b*) *In 8-24 inch samples*

Between p.p.m. P and per cent clay	−0.081
Between p.p.m. P and per cent colloid	+0.090
Between p.p.m. P and moisture-holding capacity	+0.275*

Owing to the small number of samples from below 24 inches, correlations were not calculated on them.

In the above correlations and in those to follow, the degree of significance is indicated along with the coefficient of correlation. Two asterisks mean that the coefficient is "highly significant," with odds greater than 99 : 1. One asterisk means that it is "significant," with odds between 19 : 1 and 99 : 1. Lack of an asterisk means that it is "non-significant," with odds less than 19 : 1.

The last correlation of the six is significant, but all the others are non-significant. There is no good evidence here of any effect of soil texture on the P content of the soil. If such a relationship existed, it was effectively masked by other factors.

Results with K were as follows:

(*a*) *In 0-8 inch samples*

Between p.p.m. K and per cent clay	+0.114
Between p.p.m. K and per cent colloid	+0.161
Between p.p.m. K and moisture-holding capacity	+0.286*

(*b*) *In 8-24 inch samples*

Between p.p.m. K and per cent clay	+0.073
Between p.p.m. K and per cent colloid	+0.187
Between p.p.m. K and moisture-holding capacity	+0.558**

The last correlation is highly significant, the third one significant. All six correlations are positive. It can therefore be considered that some evidence has been found to indicate a relationship between soil texture and K content. In other words, there was some tendency for an increased content of K as the soil became heavier in texture.

Results with Ca were as follows:

(*a*) *In 0-8 inch samples*

Between p.p.m. Ca and per cent clay	+0.328**
Between p.p.m. Ca and per cent colloid	+0.426**
Between p.p.m. Ca and moisture holding capacity	+0.642**

(*b*) *In 8-24 inch samples*

Between p.p.m. Ca and per cent clay	+0.437**
Between p.p.m. Ca and per cent colloid	+0.544**
Between p.p.m. Ca and moisture holding capacity	+0.738**

These results give evidence of a very close relationship between Ca and soil texture; that is, the heavier the soil, the higher the content of available Ca.

With all three elements (P, K, Ca), the total amount of each that was present in available form depended not only on soil texture but on soil depth. The heavier soils were, on the average, deeper than the lighter soils. Thus the total amounts of available K and Ca per profile were much greater with the deep soils than with the shallow soils. Even with P, where little relationship was found between the concentration of the element and the texture of the soil, somewhat more total available P was present in deep soils than in shallow soils. Correlations were calculated between the total amount of each element in pounds per acre and the total moisture-holding capacity in inches of water per profile, with results as follows:

Between pounds P and moisture capacity	+0.152
Between pounds K and moisture capacity	+0.878**
Between pounds Ca and moisture capacity	+0.857**

These last two correlations are highly significant, the first is non-significant. Thus when soil texture and soil depth were both taken into consideration, they were found to exert a marked effect on the K and Ca contents, and a minor effect on the P content.

Relation to Soil pH

Correlations obtained with soil pH were as follows:

Between p.p.m. P and pH (0-8)	−0.204*
Between p.p.m. P and pH (8-24)	−0.209*
Between p.p.m. K and pH (0-8)	+0.128
Between p.p.m. K and pH (8-24)	+0.341**
Between p.p.m. Ca and pH (0-8)	+0.527**
Between p.p.m. Ca and pH (8-24)	+0.833**
Between p.p.m. Ca and per cent lime (8-24)	+0.640**

The evidence from these correlations indicates a definite tendency for a higher pH to be accompanied by a lower content of available P. This is no doubt due to a lower solubility of P with free lime present. The pH was not low enough in any samples to cause any marked fixation of P with Fe or Al.

There was a distinct tendency for K to increase as the pH increased. Whether this was due to a direct relationship between pH and K content is not known. It was more probably due to the fact that those soils with a higher pH were for the most part those with a heavier texture. As already noted, there was a tendency toward higher K contents in heavier soils.

As would be expected, there was a very close relationship between the Ca content and the pH; in other words, the higher the Ca content, the higher the pH. This appeared to be due primarily to the effects of lime on both Ca content and pH. Even where no free lime was recorded, however, this relationship between Ca and pH was still found to hold true.

Relation to Tree Vigour

To determine the relation between nutrient content of the soil and tree vigour, the total amount of each element present in available form in the profile, expressed as pounds per acre, was correlated with the terminal lengths of the trees over a six-year period (8). The results of these correlations were as follows:

Between pounds P per acre and terminal length............	+0.134
Between pounds K per acre and terminal length............	+0.378**
Between pounds Ca per acre and terminal length............	+0.275*

It is evident from these data that greater supplies of K and Ca in the soil were accompanied by greater vigour in the trees. The same trend was evident with P, but to a lesser degree. It does not necessarily follow, however, that each of these elements was directly instrumental in increasing tree vigour. As noted in a previous paper (8), tree vigour tended to be greater in the deeper and heavier soils than in the lighter and shallower soils. Both K and Ca contents were also much greater in the deeper and heavier soils. It is thus possible that the greater vigour obtained on deeper and heavier soils might have been due to factors other than P, K or Ca.

As already noted, soil texture and soil depth can be represented adequately in combined form by the total moisture-holding capacity in the profile. When the above three correlations were re-calculated, with the effects of total moisture-holding capacity per profile eliminated, the results were + 0.103, + 0.321**, and + 0.092, respectively. The second of these correlations is highly significant, the other two non-significant. There thus remains a distinct possibility that the degree of vigour has been affected in some manner by the K content of the soil. In view of the free interaction of the many factors concerned, this possibility can be accepted as a possibility only.

Relation to Tree Yield

To determine the relation between nutrient content of the soil and tree yield, the total amount of each element present in available form in the profile, expressed as pounds per acre, was correlated with both average yield per tree and average yield of "profitable" fruit per tree over a six-year period (8). The "profitable" fruit included those fruits of Fancy or Extra Fancy grade that were within the diameter range of $2\frac{1}{4}$ to $3\frac{1}{8}$ inches. The results of these correlations were as follows:

Between pounds P per acre and total yield.................	+0.152
Between pounds P per acre and profitable yield............	+0.070
Between pounds K per acre and total yield.................	+0.374**
Between pounds K per acre and profitable yield............	+0.356**
Between pounds Ca per acre and total yield.................	+0.372**
Between pounds Ca per acre and profitable yield............	+0.462**

The first two of these correlations are non-significant, the last four highly significant. There was thus a distinct tendency for higher yields to occur where the K and Ca contents of the soil were higher. As with tree vigour, however, it does not necessarily follow that the higher yields were caused by the higher K and Ca. Highly significant correlations have already been reported (8) between the total moisture-holding capacity of

the profile and tree yields. Elimination of the effects of moisture-holding capacity from the correlations involving total yield produced the following adjusted correlations:

Between pounds P per acre and total yield	+0.095
Between pounds K per acre and total yield	+0.032
Between pounds Ca per acre and total yield	+0.045

These correlations are all non-significant and indeed very low. In other words, when the combined effects of soil texture and soil depth have been removed, no evidence of a relationship remains. There is therefore no proof of any effect of P, K or Ca on the yield. However, this cannot be accepted as final proof that actually there is no such effect. The possibility must be borne in mind that the effects of combined soil texture and soil depth on yield may be due in part to the effects of K or Ca. Evidence to date indicates, however, that the effects of soil texture and depth are due more to other factors—such as moisture content of soil, root distribution, N content, and humus content—than to P, K and Ca contents.

P and K Status

The correlation method has provided no proof of deficiencies of P or K in Okanagan soils. The question is, how do the P and K analyses on the soil samples from the 73 McIntosh plots compare with those from the fertilizer plots and from the areas of known P and K deficiencies?

From the evidence already presented (11), it can be assumed that P and K were present in sufficient amount in all of those plots of the fertilizer series that received no P or K fertilizer. The plots more especially concerned were P1, P2, K15, K46, B29 and B30. In these plots, the lowest P content in the 0-8 inch layer was 0.8 p.p.m. in Plots P1 and B30, and the lowest total P in the profile was 4 pounds per acre in Plot B30. An examination of Table 4 reveals that of the 73 plots, four showed less than 0.8 p.p.m. P in the 0-8 inch layer of soil, and seven showed less than 4 pounds P per acre in the profile. There is thus a distinct possibility that the P content might be deficient in some areas or in some soil types where field tests with fertilizers have not yet been conducted.

In those plots of the fertilizer series that received no K fertilizer, the lowest K content in the 0-8 inch layer was 64 p.p.m. in Plot B30, and the lowest total K in the profile was 292 pounds per acre in Plot K15. Of the 73 McIntosh plots, ten showed less than 64 p.p.m. K in the 0-8 inch layer, and seven showed less than 292 pounds per acre in the profile. Most of the figures were not far below 64 p.p.m. and 292 pounds, respectively. The possibility must be admitted, however, that K deficiency might exist in some Okanagan Valley soils.

The highest contents of P and K determined on surface soil samples from orchards with known P and K deficiency were 0.23 p.p.m. and 4 p.p.m., respectively. In the McIntosh plots, there were none with surface soil containing less than 0.23 p.p.m. P, and only one with surface soil containing less than 44 p.p.m. K. If 0.40 p.p.m. P and 50 p.p.m. K are to be accepted as critical values (as suggested above), then one plot can be considered as possibly deficient in P and two plots as possibly deficient in K. Once again, the evidence indicates the possibility that deficiencies of P and K have occurred in Okanagan Valley soils, but there is little if any definite proof that such is the case.

GENERAL CONCLUSIONS

No definite proof has been obtained of deficiencies of P or K in Okanagan Valley orchard soils. Some evidence has been presented, however, indicating that such deficiencies might actually have developed in some of the soil types studied. No definite relationships were found between P, K or Ca content of the soil and tree yield; nor was any response obtained from P or K fertilizers in a number of plots. However, the P and K contents in some orchard soils were found to be lower than the lowest contents in the check plots of the fertilizer plot series. They also came close, in some cases, to the P and K contents of soil samples from areas in Canada and the United States of known P or K deficiency. For the most part, the lowest P and K contents were found either in shallow, sandy soils or in orchards where the original surface soil had been lost by erosion or by levelling operations.

The evidence thus far obtained appears to be sufficient to justify the following fertilizer recommendations:

(1) Apply sufficient nitrogenous fertilizer to mature apple trees to induce an annual terminal growth of 10 to 12 inches (8).

(2) Apply phosphate as well as nitrogen to sandy or shallow soils, or to orchard soils where the original surface soil has been lost (11). The method that has been recommended from this Station for accomplishing this is to apply sufficient 16-20-0 fertilizer to induce 10 to 12 inches of terminal growth on apple trees.

(3) Apply potash, as well as nitrogen and phosphate, to soils that are *both* light and shallow (11). The recommended method is to apply sufficient 8-10-5 fertilizer to induce an annual terminal growth of 10 to 12 inches; or better still, to use 16-20-0 supplemented with some muriate of potash, a combination that is at present much cheaper here than is 8-10-5.

SUMMARY

Studies were made of the available P, K and Ca status of Okanagan Valley orchard soils. Soil samples were collected from fertilizer plots and from 73 grower-operated McIntosh blocks, at depths of 0-8, 8-24 and 24-60 inches. Soil extracts were made with CO_2-saturated water in a soil : water ratio of 1 : 2, and analyses were made for P, K and Ca. Results were expressed in terms of parts per million of dry soil at each depth, and also in terms of pounds per acre for the total depth. Determinations of moisture-holding capacity, pH, lime content, and mechanical analyses were also made.

Samples of orchard soil were obtained from areas in Canada and the United States of known P or K deficiency. These were analysed by the same procedures for P and K.

No measurable response was obtained from fertilizer applications of P and K. In those plots of the fertilizer series not receiving P or K, the lowest P contents were 0.8 p.p.m. in the surface soil and 4 pounds per acre in the profile, and the lowest K contents were 64 p.p.m. in the surface soil and 292 pounds per acre in the profile. Of the 73 McIntosh plots, four showed less than 8 p.p.m. P and ten showed less than 64 p.p.m. K in the surface soil. In the soils from the areas of known P and K deficiency, the

highest values associated with deficiency for tree fruits were 0.23 p.p.m. P and 44 p.p.m. K. Of the 73 plots, none showed less than 0.23 p.p.m. P and only one showed less than 44 p.p.m. K in the surface soil. Only one plot showed less P and only two showed less K than arbitrarily set "critical" values of 0.40 p.p.m. P and 50 p.p.m. K. There was thus good indication of the possibility of P and K deficiencies in some soil types not yet included in the fertilizer tests, but no definite proof that such deficiencies actually existed.

Correlations were calculated between the P, K and Ca contents of the soil on the one hand and tree vigour and yield on the other hand. Both K and Ca showed distinct positive correlations with both vigour and yield; however, when adjustments were made for soil texture and depth, almost all of the correlations lost their significance. There was no definite evidence of any effect of P, K or Ca on tree vigour or yield.

Both the P and K contents were higher in the surface soil than in the subsoil. In sandy soils, Ca was higher in the surface soil; but in heavy soils, Ca and free lime were much higher in the subsoil. There was little correlation between soil texture and P content; however, both K and Ca were present in larger quantity in heavy soils than in sandy soils. The pH showed a negative correlation with the P content, and positive correlations with the K, Ca, and lime contents.

ACKNOWLEDGMENTS

A number of workers—too numerous to mention—have given the author valuable help by collecting and shipping soil samples from areas of known P and K deficiency. The author wishes to give special thanks for this help to the following: B. A. Dixon in British Columbia; M. B. Davis, H. Hill and J. R. van Haarlem in Ontario; A. B. Burrell and Ora Smith in New York; J. K. Shaw in Massachusetts; R. D. Anthony and C. O. Dunbar in Pennsylvania; J. R. Magness, H. L. Crane and Leon Havis in Maryland; J. H. Painter in Georgia; G. F. Potter in Louisiana; E. L. Proebsting in California; R. E. Stephenson in Oregon and W. J. Clore in Washington.

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APPENDIX

TABLE 4.—DATA FROM McINTOSH PLOT SOILS

Plot No.	Soil depth	M.C.F.*	pH	P content		K content		Ca content		Lime content
				At each depth	Profile total	At each depth	Profile total	At each depth	Profile total	
	in.	in.		p.p.m.	pounds	p.p.m.	pounds	p.p.m.	pounds	%
P1	0-8	3.59	7.61	0.8		69		485		1.4
	8-24	3.43	8.19	0.2		48		559		5.2
	24-60	3.10	8.29	0.2	5	49	1028	469	9904	2.8
P2	0-8	3.58	6.85	3.3		105		187		0.0
	8-24	3.48	7.88	1.2		57		455		2.1
	24-60	3.43	8.08	0.4	20	51	1196	484	8736	5.2
P3	0-8	3.63	6.28	11.9		81		183		0.0
	8-24	3.32	7.47	1.1		51		447		0.1
	24-60	3.03	8.13	0.6	45	46	1040	565	9652	3.9
P4	0-8	3.52	6.36	9.7		132		145		0.0
	8-24	3.31	7.75	1.2		56		542		0.6
	24-60	3.43	8.13	0.3	36	52	1276	590	10360	5.4
P5	0-8	3.45	6.67	2.9		132		205		0.0
	8-24	3.28	7.93	0.5		59		498		1.6
	24-60	3.05	8.33	0.4	15	48	1244	613	10552	3.0
P6	0-8	3.37	6.68	5.6		110		193	740	0.0
	8-24	1.98	6.35	0.3	17	25	424	42		0.0
P7	0-8	2.50	6.68	3.2		78		141		0.0
	8-24	2.85	6.73	1.1	14	37	404	64	716	0.0
P9	0-8	3.22	7.13	3.3		119		172		0.0
	8-24	3.32	7.89	0.4		55		383		0.1
	24-60	3.69	8.19	0.3	15	46	1164	488	8360	4.9
P10	0-8	2.96	7.40	4.3		117		164		0.0
	8-24	2.83	7.79	1.2		61		240		0.0
	24-60	3.50	8.14	0.7	26	48	1212	585	8736	4.5
S10	0-8	2.24	6.78	0.6		59		108		0.0
	8-24	1.42	6.64	0.1	2	22	272	38	492	0.0
S12	0-8	3.37	6.68	0.9		62		146	1768	0.0
	8-24	1.98	6.35	0.5	5	32	336	259		0.0
T2	0-8	2.94	6.11	4.0		162		354		0.0
	8-36	2.55	8.06	0.6	17	78	904	473	5360	3.3
T3	0-8	2.53	6.15	3.6		101		263		0.0
	8-24	1.52	7.31	0.3	11	25	404	66	1052	0.0
T6	0-8	2.65	7.64	2.7		98		307		0.0
	8-24	1.77	7.48	0.5	10	29	416	109	1400	0.0
T7	0-8	2.19	7.39	2.2		70		212		0.0
	8-24	1.21	7.28	0.4	8	21	300	87	1028	0.0
T8	0-8	3.10	7.27	6.7		100		295		0.0
	8-30	2.27	7.86	0.8	24	39	556	398	3708	0.6
T9	0-8	2.44	7.22	5.3		83		167		0.0
	8-24	1.86	7.29	0.8	19	36	412	98	968	0.0

* M.C.F.—Moisture holding capacity of the soil, expressed in terms of inches of water per foot of soil.

TABLE 4.—DATA FROM MCINTOSH PLOT SOILS—*Continued*

Plot No.	Soil depth	M.C.F.*	pH	P content		K content		Ca content		Lime content
				At each depth	Profile total	At each depth	Profile total	At each depth	Profile total	
	in.	in.		p.p.m.	pounds	p.p.m.	pounds	p.p.m.	pounds	%
K2	0-8	2.87	6.10	1.1		81		130		0.0
	8-20	1.95	6.57	0.2	3	32	344	43	520	0.0
K6	0-8	3.00	6.35	2.0		92		122		0.0
	8-18	1.58	6.77	0.3	6	32	352	28	416	0.0
K7	0-8	2.96	6.27	2.4		79		93		0.0
	8-24	2.85	6.67	0.6		24		66		0.0
	24-44	2.95	7.84	0.9	16	18	460	380	3132	0.5
K8	0-8	3.84	7.02	1.6		87		156		0.0
	8-24	4.00	7.64	0.5		28		420		2.5
	24-60	4.22	7.96	0.2	10	43	896	351	7612	2.2
K9	0-8	3.08	6.06	3.7		92		81		0.0
	8-24	2.75	6.90	0.9		46		81		0.0
	24-35	2.65	8.34	0.9	18	46	656	299	1744	0.9
K10	0-8	2.76	6.73	1.4		48		89		0.0
	8-27	1.16	6.49	0.2	5	5	160	19	356	0.0
K11	0-8	2.89	6.46	10.1		79		157		0.0
	8-22	1.01	6.36	0.5	29	20	312	27	504	0.0
K12	0-8	2.74	5.87	8.8		105		82		0.0
	8-23	1.12	6.34	0.5	26	20	388	24	320	0.0
K13	0-8	2.84	6.30	8.2		90		106		0.0
	8-25	1.26	6.34	1.1	28	33	424	25	424	0.0
K14	0-8	2.78	5.99	8.9		180		88		0.0
	8-24	1.25	6.36	0.8	28	26	620	33	412	0.0
K15	0-8	2.40	6.66	2.0		74		98		0.0
	8-23	1.07	6.46	0.2	6	19	292	20	360	0.0
K16	0-8	3.22	6.70	3.1		114		115		0.0
	8-24	3.20	6.96	0.8		56		142		0.0
	24-54	3.73	7.98	0.6	19	50	1104	381	4876	3.0
K17	0-8	3.50	6.64	3.8		119		113		0.0
	8-24	3.73	6.54	0.8		56		60		0.0
	24-48	4.12	7.80	0.9	22	30	860	485	4500	2.6
K18	0-8	4.18	6.72	1.9		98		169		0.0
	8-24	4.45	7.74	0.3		25		244		2.7
	24-60	4.22	8.23	0.1	9	53	1028	316	4912	3.3
K21	0-8	2.73	6.75	2.8		115		120		0.0
	8-26	2.54	6.74	0.3	10	57	652	60	680	0.0
K22	0-8	2.65	5.83	1.8		70		69		0.0
	8-22	1.60	6.14	0.1	5	19	276	18	268	0.0
K24	0-8	2.78	6.54	2.1		90		101		0.0
	8-24	1.97	6.64	0.2		44		49		0.0
	24-57	2.58	8.02	0.4	11	45	972	317	4016	0.7
K25	0-8	4.08	6.53	1.3		81		132		0.0
	8-24	4.58	7.35	0.5		58		404		1.4
	24-60	4.58	7.78	0.1	7	58	1220	364	6896	2.3

TABLE 4.—DATA FROM McINTOSH PLOT SOILS—*Continued*

Plot No.	Soil depth	M.C.F.*	pH	P content At each depth	P content Profile total	K content At each depth	K content Profile total	Ca content At each depth	Ca content Profile total	Lime content
	in.	in.		p.p.m.	pounds	p.p.m.	pounds	p.p.m.	pounds	%
K27	0-8	3.35	6.61	0.9		92		151		0.0
	8-40	0.95	6.66	0.2	4	17	424	20	616	0.0
K39	0-8	1.23	6.56	0.4		30		57		0.0
	8-29	1.25	6.30	0.1	2	17	200	27	340	0.0
K44	0-8	2.86	5.78	0.8		78		120		0.0
	8-22	0.97	6.10	0.1	2	5	232	25	436	0.0
K46	0-8	2.74	6.27	1.6		80		94		0.0
	8-22	1.29	6.51	0.1	5	18	296	20	344	0.0
K48	0-8	4.26	6.63	1.7		84		177		0.0
	8-24	4.35	7.65	1.2		64		339		1.7
	24-60	4.35	8.22	0.1	13	18	780	224	4968	3.2
K49	0-8	4.32	6.69	0.7		65		154		0.0
	8-24	4.62	7.95	0.1		53		294		3.6
	24-60	4.67	7.63	0.5	8	54	1104	422	7084	2.0
K51	0-8	2.79	5.67	8.4		80		96		0.0
	8-21	1.32	6.15	0.5	24	25	320	29	380	0.0
K53	0-8	2.44	6.04	0.6		57		81		0.0
	8-28	1.09	5.98	0.1	2	30	352	21	356	0.0
K54	0-8	2.86	6.40	0.7		61		83		0.0
	8-25	0.94	6.36	0.1	2	15	248	22	344	0.0
B1	0-8	3.05	6.21	2.2		91		78		0.0
	8-24	2.88	6.69	0.5		46		94		0.0
	24-57	3.23	8.01	0.5	15	43	960	325	3092	0.9
B29	0-8	2.85	6.93	1.4		68		106		0.0
	8-30	2.60	7.10	0.3	6	35	436	51	660	0.0
B30	0-8	2.92	6.21	0.8		64		74		0.0
	8-27	2.68	6.68	0.3	4	33	380	59	568	0.0
B31	0-8	2.92	5.82	16.4		87		111		0.0
	8-27	2.70	6.78	2.6	60	36	460	80	804	0.0
B33	0-8	2.70	6.60	2.2		63		87		0.0
	8-24	2.65	6.44	0.5		36		57		0.0
	24-36	2.38	6.93	0.5	10	36	504	48	728	0.0
B34	0-8	2.58	6.47	3.3		95		124		0.0
	8-24	2.65	6.58	0.9		61		82		0.0
	24-38	1.34	6.65	0.5	16	25	692	22	872	0.0
B36	0-8	3.02	6.02	1.3		59		85		0.0
	8-31	1.67	7.19	0.3	5	23	332	149	1372	0.0
B37	0-8	3.12	6.12	0.8		58		82		0.0
	8-27	1.88	6.62	0.2	3	23	300	71	668	0.0
B38	0-8	2.98	6.56	1.4		63		108		0.0
	8-27	2.60	6.32	0.2	5	31	364	56	644	0.0
G17	0-8	2.06	7.02	1.5		64		156		0.0
	8-24	1.66	7.31	0.5		34		84		0.0
	24-40	2.56	8.21	0.3	8	43	580	393	2960	1.5

TABLE 4.—DATA FROM McINTOSH PLOT SOILS—*Concluded*

Plot No.	Soil depth	M.C.F.*	pH	P content		K content		Ca content		Lime content
				At each depth	Profile total	At each depth	Profile total	At each depth	Profile total	
	in.	in.		p.p.m.	pounds	p.p.m.	pounds	p.p.m.	pounds	%
G18	0-8	2.37	6.36	10.1		98		102		0.0
	8-24	2.03	6.79	1.7		48		60		0.0
	24-44	2.32	7.73	0.4	38	38	768	215	2024	0.1
G19	0-8	4.10	7.12	2.5		122		584		0.0
	8-24	3.67	7.60	0.7		48		724		1.0
	24-57	3.46	8.12	0.2	12	53	1168	494	9040	6.2
G20	0-8	4.08	7.15	1.9		136		715		0.0
	8-24	4.20	7.68	0.3		36		881		2.7
	24-60	4.20	7.92	0.1	7	25	856	774	15640	4.0
G26	0-8	2.92	6.94	2.8		94		95		0.0
	8-24	2.82	8.12	0.8		53		502		0.1
	24-60	2.73	8.23	0.6	19	45	276	428	7780	0.2
G42	0-8	3.27	6.95	1.8		100		121		0.0
	8-24	3.03	6.63	0.3		53		70		0.0
	24-60	2.73	8.18	1.4	23	56	1224	488	6388	1.4
G50	0-8	2.76	5.95	1.8		74		66		0.0
	8-24	2.38	6.91	0.2		45		38		0.0
	24-60	2.70	8.24	0.9	17	44	964	416	5232	0.3
W2	0-8	3.82	6.56	1.2		88		161		0.0
	8-24	4.10	7.25	0.1		71		351		0.0
	24-48	3.65	7.93	0.1	5	58	1080	491	6268	0.9
W4	0-2	2.53	6.13	2.7		84		71		0.0
	8-24	2.48	6.62	0.5		47		57		0.0
	24-60	2.13	6.95	0.6	17	40	956	40	972	0.0
W5	0-8	2.54	6.50	2.1		83		88		0.0
	8-24	1.88	6.80	0.2	7	34	400	37	432	0.0
W6	0-8	2.26	6.45	1.0		70		52		0.0
	8-24	1.77	6.50	0.2	4	34	368	35	328	0.0
W7	0-8	2.38	6.11	1.0		79		64		0.0
	8-30	2.26	6.64	0.2	5	45	544	61	620	0.0
W8	0-8	2.82	6.50	3.5		105		125		0.0
	8-24	2.46	6.81	0.3		44		48		0.0
	24-52	3.83	8.27	0.3	13	44	928	379	4124	2.5
W9	0-8	3.92	6.63	3.7		145		203		0.0
	8-24	4.12	6.80	0.5		53		113		0.0
	24-60	4.05	8.01	0.2	15	47	1236	427	6268	3.2
W10	0-8	3.18	6.57	3.2		106		157		0.0
	8-24	2.68	6.42	0.8		40		59		0.0
	24-60	3.20	8.24	0.2	15	48	1112	328	4612	0.0
O14	0-8	3.28	6.63	9.2		113		135		0.0
	8-33	2.65	7.79	0.4	28	46	688	407	3752	0.0
O15	0-8	1.58	6.33	1.7		93		66		0.0
	8-24	1.76	6.20	0.1	5	27	392	36	368	0.0
O17	0-8	2.73	6.44	2.4		91		129		0.0
	8-24	2.41	6.57	0.5	9	47	496	77	756	0.0
O18	0-8	1.93	7.01	1.7		79		94		0.0
	8-24	1.70	7.15	0.2	6	27	356	51	524	0.0
O19	0-8	2.19	7.42	1.9		85		167		0.0
	8-24	1.33	7.40	0.1	6	31	392	70	816	0.0

THE EFFECT OF LOOSE SMUT ON THE VIABILITY OF ARTIFICIALLY INOCULATED BARLEY SEEDS[1]

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[Received for publication January 14, 1948]

INTRODUCTION

Loose smut of barley caused by *Ustilago nuda* (Jens.) K. and S. does not usually result in serious yield losses in western Canada. However, it is difficult to control and causes serious inconvenience in seed production. Resistance to this disease would be desirable in new barley varieties. Accordingly, varietal tests were instituted at this Station in 1944 to find parental material that carried resistance to the disease. When artificially inoculated seeds were planted many failed to emerge. Tests were then conducted to determine whether or not the loose smut organism was responsible for the reduced stands, and if so, whether or not varietal differences existed.

LITERATURE REVIEW

Several workers have encountered poor stands in seed artificially inoculated with loose smut.

Thren (6), using a dry spore method of inoculation, found that a high concentration of viable spores in the inoculum resulted in reduced stands and weak seedlings. He was able to increase stands and maintain good infection by reducing the live spore concentration. Some of his results were as follows:

Spore concentration	Per cent stand	Per cent infection
%	%	%
100	33.5	52.8
10	52.7	44.9
5	63.4	52.3
1	68.1	50.8
0.1	81.3	19.1
0	87.8	0.6

It will be noted that when a one per cent spore concentration was used there was still a considerable reduction in stand. In a later paper (7) Thren found that, with certain varieties, a low rate of infection at maturity was correlated with a heavy loss of inoculated material. This loss was partly due to failure of inoculated florets to develop seeds, but especially to failure of inoculated seeds to germinate. He considered that the resistance of these barleys was equivalent to hypersensitiveness to inoculation with the fungus. Such types were frequently found among Japanese varieties. Although with German varieties, Thren was able to decrease the loss of inoculated material by using the improved methods of inoculation described above, he was unable to do so with Japanese varieties.

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Livingston (1) also encountered poor stands from inoculated seed, and considered that infected plants were weakened by the loose smut organism.

Shands and Schaller (4) found that stands varied from year to year even though the same method of inoculation was used. By treating inoculated seed with an organic mercury dust they were able to increase germination and vigour. The dust, presumably, protected the seed from secondary fungi.

Oort (2), working with the loose smut disease of wheat, encountered symptoms of hypersensitiveness. Hypersensitive plants, when grown in the greenhouse, were inhibited in growth and frequently died in the two- or three-leaf stage. Those that survived remained small and produced little, if any, grain but were almost invariably free from smut. When grown in the field these plants usually failed to emerge. Oort concluded that two different principles were involved in the relationship of host to parasite, namely, resistance or susceptibility, and hypersensitiveness or non-hypersensitiveness. He attempted to explain the varietal reactions on the basis of genetic factors. The temperature prevailing during the ripening of the seed strongly influenced the degree of hypersensitiveness. For example, when Race 1 was used the degree of hypersensitiveness was about three times as high at 24° as it was at 13° C.

Vanderwalle (8) also worked with loose smut of wheat and found no correlation between the presence of the fungus in the seed and the ability of the seed to germinate. In so far as the authors are aware, he is the only worker who has not found a reduction in the germination of infected seed.

INOCULATION TECHNIQUE

Inoculum was collected from as many varieties as possible in the barley nursery plots. These varieties had been introduced over a period of years from many areas and were frequently infected with loose smut on arrival. Very probably the inoculum represents most of the prevailing forms of the organism.

The method of inoculation was similar to that outlined by Poehlman (3). The spores were removed from the rachis, put through a coarse sieve, and mixed with water in the proportions, one gram of spores to fifty c.c.'s of water. The suspension was mixed thoroughly and strained through cheesecloth. A one-ounce rubber bulb and a No. 24 hypodermic needle were used to inject the spore suspension into the florets. Inoculations were made one or two days after pollination of the earliest florets. All florets were inoculated except the small ones at the base and the tip of the spike.

EFFECT OF INOCULATION ON VIABILITY

A test was designed to determine whether or not reduced stands from inoculated seed were due to the loose smut organism or to the method of inoculation. Four varieties of barley were seeded in the greenhouse in January, 1946, and treated as follows: Twenty heads of each variety were inoculated with loose smut; twenty with tap water; the lemmas of twenty were punctured with the needle; and twenty were left as checks. The inoculated seeds were grown in the field, using a split plot design with four replicates.

A summary of the data obtained is presented in Table 1. The results clearly show that the presence of the loose smut organism caused a substantial reduction in stand. Inoculating with water or puncturing the lemmas had no significant effect on stand. There is evidence of varietal differences in the amount of reduction that took place. The stand of Conway, for example, was reduced much more than that of Plush.

TABLE 1.—STAND AND PER CENT INFECTION OF BARLEY VARIETIES INOCULATED WITH LOOSE SMUT COMPARED WITH UNINOCULATED CHECKS, CHECKS INOCULATED WITH WATER AND CHECKS IN WHICH THE LEMMA WAS PUNCTURED WITH A NEEDLE

Treatment	Variety	Per cent stand	Per cent infection
Check	Plush	78.0	0.0
Check	Conway	79.4	0.0
Check	Tregal	74.8	0.0
Check	Regal	69.5	0.0
Average		75.4	0.0
Lemma punctured	Plush	80.2	0.0
Lemma punctured	Conway	70.0	0.0
Lemma punctured	Tregal	80.8	0.0
Lemma punctured	Regal	70.8	0.0
Average		75.4	0.0
Inoculated with water	Plush	81.7	0.6
Inoculated with water	Conway	87.5	0.7
Inoculated with water	Tregal	75.7	0.3
Inoculated with water	Regal	71.7	1.7
Average		79.2	0.8
Inoculated with smut	Plush	45.2	63.9
Inoculated with smut	Conway	24.5	75.6
Inoculated with smut	Tregal	31.1	19.2
Inoculated with smut	Regal	43.7	19.7
Average		36.1	44.6

VARIETAL DIFFERENCES IN VIABILITY

Data were obtained on the stand and infection of 21 varieties in three different tests over the period 1944-46. Approximately 400 inoculated seeds were sown in each test. Unfortunately no comparable lots of seed were grown as checks. In the statistical analyses of the data obtained the value one was added to each of the figures for per cent stand and per cent infection in order to eliminate zero readings. The values obtained were converted to sine^2 θ and analysed by variance and covariance.

A summary of the actual data obtained is presented in Table 2, the variance analyses in Table 3, and the covariance analysis in Table 4.

Highly significant varietal differences were obtained for both stand and infection. Differences due to tests were significant for stands but not for infections. This would indicate that stands are more subject to environmental influences than infections.

The results of the covariance analysis showed that there was no relationship between stand and infection within varieties, since the difference between the mean square for error before and after adjustment was not significant. In other words, variations within varieties for per cent infection were not due to differences in stand. In addition, the covariance analysis showed a significant positive relationship between stand and infection between varieties, since the difference between the regressions within and between varieties was highly significant. That is, varieties with the best stands had the highest infection percentages. Exceptions, however, were found. For example, Warrior had a high degree of resistance and a fairly good stand, while Newal was very susceptible and had a poor stand.

TABLE 2.—STAND AND INFECTION PERCENTAGES OF BARLEY VARIETIES INOCULATED WITH LOOSE SMUT

Variety	Per cent stand				Per cent infection			
	Test 1	Test 2	Test 3	Av.	Test 1	Test 2	Test 3	Av.
Atlas	62.4	72.0	65.0	66.5	51.8	57.0	61.8	56.9
Rika	59.4	54.0	80.7	64.7	44.2	50.0	60.6	51.6
Plush	40.5	84.0	68.6	64.4	46.8	47.6	38.7	44.4
Trabut	61.1	46.0	74.2	60.4	53.2	56.5	43.1	50.9
Vantage	57.9	59.0	64.2	60.4	34.8	49.2	45.3	43.1
U. of S. 8	52.1	60.0	61.4	57.8	34.0	43.3	34.7	37.3
Mars	69.4	46.0	53.6	56.3	31.0	19.6	27.9	26.2
Warrior	44.8	58.0	63.6	55.5	6.4	0.0	1.6	2.7
Brandon 1360	46.7	56.0	61.4	54.7	54.0	44.6	61.0	53.2
Brandon 112	50.0	60.0	47.9	52.6	51.2	40.0	39.8	43.7
O.A.C. 21	38.1	55.0	64.3	52.5	0.0	20.0	23.3	14.4
Hannchen	39.8	53.0	60.7	51.2	56.5	51.0	59.4	55.6
Tall Comfort	39.6	53.0	53.6	48.7	8.9	7.5	6.9	7.8
Regal	33.1	60.0	52.8	48.6	18.9	15.0	17.5	17.1
Texan	49.4	40.0	56.4	48.6	0.0	2.5	2.5	1.7
Montcalm	40.5	48.0	56.4	48.3	52.6	18.8	39.1	36.8
Trebi	57.7	39.0	42.1	46.3	0.0	5.1	5.2	3.4
Velvon	39.3	49.0	45.7	44.7	3.8	14.3	22.0	13.4
Titan	39.4	49.0	42.1	43.5	0.0	0.0	0.0	0.0
Newal	32.5	40.0	34.3	35.6	47.8	50.0	51.1	49.6
Ezond	34.2	26.0	19.3	26.5	0.0	0.0	0.0	0.0

TABLE 3.—ANALYSES OF VARIANCE OF STAND AND INFECTION

Variation due to	Degrees of freedom	Stand		Infection	
		Mean square	F value	Mean square	F value
Tests	2	137.40	4.30*	28.17	1.07
Varieties	20	99.14	3.10**	757.25	28.88**
Error	40	31.96	—	26.22	—

* Exceeds the 5 per cent point.
** Exceeds the 1 per cent point.

TABLE 4.—ANALYSIS OF COVARIANCE

Source	Deg. of freed.	Sums of squares and products			Errors of estimate			
		Sx^2	Sxy	Sy^2	Sums squares	D.F.	Mean square	F
Total	62	3,535.77	3,275.48	16,250.24				
Tests	2	274.79	110.88	56.34				
Varieties	20	1,982.77	3,128.33	15,144.99	10,209.25	19		
Error	40	1,278.21	36.27	1,048.91	1,047.88	39	26.869	
Var. plus error	60	3,260.98	3,164.60	16,193.90	13,122.84	59		
Difference for testing adjusted variety means					12,074.96	20	603.748	22.47**
Difference between regressions within and between varieties (b_1—b_2)					1,865.71	1	1,865.71	69.44**
Difference between errors before and after adjustment					1.03	1	1.03	0.04

r_1 (Between varieties) = 0.571**.
b_1 (Between varieties) = 1.58.
r_2 (Within varieties) = 0.031.
b_2 (Within varieties) = 0.028.

** Exceeds the 1 per cent point.

DESTRUCTION OF EMBRYOS

In the course of work on the host-parasite relationship evidence was obtained that the mycelium of the loose smut disease was capable of completely destroying barley embryos. The destruction or weakening of them probably accounts for the losses in viability that have been noted. A brief description of the relevant parts of this investigation follows.

In 1945, twenty varieties were inoculated in the field. When harvested, the inoculated seed from each spike was divided into two lots. This was done by placing the seeds from one side of each spike in one lot and those from the other in the second lot. There were approximately 100 seeds of each variety in each lot.

One lot of seed was planted in the greenhouse and the stand and infection noted.

The second lot was examined for the presence of mycelium in the embryos by means of the "whole embryo method" described by Simmonds (5). Using this technique the embryos are removed from the endosperms by treatment with a sodium hydroxide solution. They are then dehydrated in alcohol, cleared in cedar oil and examined without staining or sectioning. In the present study, glycerine was used as a clearing agent instead of oil, and as a result, it was not necessary to dehydrate with alcohol. The glycerine modification simplified the technique, but specimens could not be kept in good condition for as long a period of time.

When the embryos were examined, it was found that some had been almost completely destroyed by the invading mycelium. Such badly injured embryos would have little chance of producing seedlings. No attempt was made to determine the number of badly damaged embryos in

TABLE 5.—PERCENTAGE OF EMBRYOS RECOVERED BY THE WHOLE EMBRYO TECHNIQUE AND PERCENTAGE STAND FROM COMPARABLE LOTS OF SEED GROWN IN THE GREENHOUSE

Variety	Per cent embryos recovered	Per cent stand
Plush	92	84
Glacier	78	65
Lico	87	64
Warrior	98	58
Brandon 1360	80	56
O.A.C. 21	80	55
Colsess	84	53
Hannchen	75	53
Tall Comfort	83	53
Velvon	64	49
Titan	70	49
Rex	66	47
Mars	72	46
Trabut	98	46
Newal	83	40
Trebi	70	39
Vance Smyrna	35	30
Ezond	38	26
Tregal	36	20
Conway	54	15
Average	72	47

$r = 0.769$ (Significant at the 1 per cent level).

relation to more normal appearing ones. Generally speaking, there was a gradation within each variety from severe injury to no evidence of mycelial growth. However, it was noted that where embryos of resistant types were infected, the amount of apparent damage was much greater than in the more susceptible types.

When the embryos were removed from the endosperms, every precaution was taken to recover all of them. Despite these precautions, only a portion of them were recovered. From a physical examination it appeared that the loss in recovery was primarily due to destruction by the loose smut organism so that the embryo disintegrated and was lost in the recovery process. The percentage of embryos recovered was compared with the percentage stand of the first lot of seed grown in the greenhouse. The data are presented in Table 5. A highly significant correlation coefficient of 0.769 was obtained between the two variables. This is further evidence in support of the hypothesis that the loose smut organism is capable of destroying the embryos of barley. The mean percentage of embryos recovered was 72 and the mean percentage stand was 47. The difference was probably due to the fact that a portion of the embryos recovered were badly damaged, and to mortality from other causes, such as secondary disease organisms.

DISCUSSION

The results of this study are in agreement with other investigators that inoculating barley with loose smut results in lowered viability of the seed. The reduction is apparently due to the mycelial growth destroying the embryo or, as Oort (2) has termed it in wheat, the plant is hypersensitive to the organism. The amount of reduction appears to depend on a number of factors.

Variety

The present investigation has shown that varieties differ in the amount of damage they sustain.

Spore Load

Heavy spore loads cause greater reductions according to Thren (6).

Environmental Conditions Following Inoculation

Oort (2) has shown that temperature at this time influences the degree of hypersensitiveness of wheat to loose smut and very probably the same thing occurs in barley.

Environmental Conditions Following Seeding

As would be expected, practically all investigations, including the present one, show differences between tests that are probably due to environmental conditions at the time of germination and early seedling growth.

Physiologic Specialization

Oort (2) found that symptoms of hypersensitiveness were induced by five out of ten collections representing three out of six physiologic races of loose smut on wheat. Thren (7), on the other hand, working with two races of loose smut of barley, found no significant difference between them in decrease in germinability of inoculated seeds of the differential host, Mittlauer Hanna. Different results might easily have been obtained using other races or host varieties.

It is obvious that the amount of infection that a variety exhibits at maturity is dependent not only on its inherent resistance, but also on its ability to grow when the embryo is infected. In this study, these factors were positively associated, but the association was not close. Somewhat similar results were obtained by Thren (7). The interrelationships of these two phenomena need further study. It is hoped that a genetical study, now under way at this Station, will throw further light on the problem.

The reduced viability of inoculated seed probably explains the results of certain cultural experiments on this disease. For example, deep seeding has frequently been found to result in less loose smut in the crop than shallow seeding. It would be expected that fewer infected plants would emerge from the greater depth.

SUMMARY

Four varieties of barley were treated as follows. One lot of each variety was florally inoculated with chlamydospores of the loose smut organism *Ustilago nuda* (Jens.) K. and S. by means of a hypodermic needle; a second was inoculated with tap water; in a third the lemmas were punctured with the needle; and the fourth was left as a check. Compared with the check, the emergence of seeds inoculated with the organism was much lower, whereas those inoculated with water, or where the lemma was punctured were equally as high.

Approximately 400 seeds of each of 21 varieties were inoculated in a second experiment. In all, three such tests were conducted. Significant differences due to varieties and to tests were established. A significant positive relationship was established between stand and infection at maturity.

An examination of the embryos of inoculated seed showed that some embryos were almost completely destroyed by the invading mycelium. The percentage of embryos that could be recovered after treatment of the seed with sodium hydroxide was noted. Non-recovered embryos were presumed to have been destroyed by the fungus. A highly significant positive correlation of 0.769 was found between percentage of embryos recovered and percentage stand of comparable lots of seed.

It is pointed out that the amount of infection present on a variety at maturity depends not only on inherent resistance, but also on the ability of the seed to germinate and grow when the embryo is infected. Both factors need to be taken into consideration when the genetics of loose smut resistance in barley are studied.

ACKNOWLEDGMENTS

The authors wish to express their thanks to Ruby I. Larson, Cytogeneticist, Dominion Experimental Station, Swift Current, for translating certain publications, and for assistance in the examination of inoculated embryos. They also wish to express their appreciation to P.M. Simmonds, Officer-in-Charge, Dominion Laboratory of Plant Pathology, Saskatoon, for reading the manuscript.

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